2-P

FZK-351-4
MARCH 1969

NERVA IRRADIATION PROGRAM

GTR Test 21

Volume 4 — Effect of Radiation on Structural Materials Tested at Cryogenic and Elevated Temperatures

Prepared for the
Space Nuclear Propulsion Office
of the
National Aeronautics and Space Administration
Cleveland, Ohio 44135

Contract No. AF29(601)-7077
(Supplement 10)

NUCLEAR AEROSPACE RESEARCH FACILITY

operated by

GENERAL DYNAMICS
Fort Worth Division

FZK-351-4
MARCH 1969

NUCLEAR AEROSPACE RESEARCH FACILITY

NERVA IRRADIATION PROGRAM

GTR Test 21

Volume 4—Effect of Radiation on Structural Materials Tested at Cryogenic and Elevated Temperatures

R. H. McDaniel
N. D. King
J. E. Warwick
J. H. Lewis

**Prepared for the
Space Nuclear Propulsion Office
of the
National Aeronautics and Space Administration
Cleveland, Ohio 44135**

Contract No. AF 29(601)-7077
Supplement 10

GENERAL DYNAMICS
Fort Worth Division

FOREWORD

The radiation effects study described in this document was performed at the Nuclear Aerospace Research Facility (NARF) of the Fort Worth Division of General Dynamics for the Space Nuclear Propulsion Office, Cleveland, Ohio (SNPO-C) under Statement of Work No. 5 (Attachment I), Contract AF29(601)-7077, Supplemental Agreement No. 10. Test specimens and test specifications were provided by Aerojet-General Corporation, Sacramento, California.

The work was performed as a part of GTR Test 21, the most recent of a series of continuing tests being conducted on materials and components under consideration for use in the NERVA program. The first three volumes of GTR-21 (FZK-351-1, -2, -3) are subtitled:

Vol. 1 - Evaluation of a Polargraphic Hydrogen-Gas Detector (15 Dec 67)

Vol. 2 - Nuclear-Radiation-Induced Conversions of Parahydrogen to Orthohydrogen (15 May 68)

Vol. 3 - Thermal Conductivity and Electrical Resistivity of Selected NERVA Materials (30 Sept 68)

The present document, Volume 4, describes Cryogenic Structural Materials Test 37R018 and High-Temperature Structural Materials Test 37R017. The complete mechanical-properties data are given; the results of the metallographic studies are to be reported in Volume 5.

SUMMARY

The experiment described in this report was designed to determine the effects of nuclear radiation on the mechanical and metallurgical properties of several structural materials of potential use in the NERVA (Nuclear Engine for Rocket Vehicle Applications). The tests were performed at the Nuclear Aerospace Research Facility (NARF) of the Fort Worth Division of General Dynamics in accordance with specifications (RN-S-0411) provided by Aerojet-General Corporation, Sacramento, California.

The materials tested were of two categories - cryogenic structural materials (Test 37R018) and high-temperature structural materials (Test 37R017). In both cases, test specimens provided by AGC were irradiated for 2310 MWh (between 13 October and 3 November 1967) by means of the Ground Test Reactor (GTR). Mechanical-properties tests were then performed in the laboratory under the specified test conditions.

The cryogenic structural materials were Aluminum 7039-T61 (parent and as welded), Aluminum 7039-T64 (parent, and welded and treated to T61), and Hastelloy X (parent and weldment). The Aluminum 7039 specimens were fabricated in two configurations, round-unnotched and flat-notched; the Hastelloy X specimens were fabricated only in the round-unnotched configuration. With the exception of several Aluminum 7039 specimens that were annealed

for 1 hour at either 440° or 540°R, the specimens were maintained in liquid nitrogen throughout the irradiation, storage, and tensile testing. All of the specimens were tested between 13-21 December 1967. The tensile data and stress-strain plots are given in Section IV; a summary of the data is presented in Section II. A t-test of significance was used to evaluate the effects of the various test conditions.

The high-temperature structural materials were René 41, Waspaloy, and Inconel 718. Round-unnotched specimens were irradiated in water to three different levels of thermal-neutron fluence and subsequently tensile-tested (between 4 March and 2 April 1968) at several elevated temperatures. René 41 was tested at 1660°R at strain rates of 0.0013, 0.013, and 0.13 in./in./min, and at 1860°R at a strain rate of 0.0013 in./in./min. Waspaloy was tested at 1560°, 1660°, and 1860°R at a strain rate of 0.0013 in./in./min, and at 1660°R at a strain rate of 0.013 in./in./min. Inconel 718 specimens having boron contents of 0.6, 37, or 46 ppm were tested at temperatures of from 1360° to 1660°R; most tests were at a strain rate of 0.0013 in./in./min. The tensile data and stress-strain curves are given in Section VI; a summary of the data is presented in Section II. The results include t-tests of significance for comparing the effects of the various test conditions.

Stress-rupture tests were also performed on specimens of Waspaloy and Inconel 718 at test temperatures of 1660° and 1760°R.

These tests were conducted between 19 March and 8 June 1968; the results are given in Section VI and are summarized in Section II.

ACKNOWLEDGMENTS

The authors wish to acknowledge the cooperation and contribution of the following General Dynamics Fort Worth Division personnel who participated in this study:

Messrs. G. W. Thiebaud, J. Pugh, and G. E. Irby for their assistance in the tensile tests, bench measurements, and data reduction.

Messrs. W. M. Laney and J. B. McGoodwin for their assistance in bench measurements.

Mr. M. R. Self for his assistance in polishing of metallography specimens, bench measurements, and data reduction.

Mr. J. B. Wattier for his assistance in programming the computations and in the statistical analysis.

Mr. W. E. Dungan for providing the mapping data.

In addition, Mr. J. E. Stadig, of Aerojet General Corporation, is to be commended for his technical advice and assistance during the tensile and stress-rupture tests.

TABLE OF CONTENTS

TABLE OF CONTENTS (Cont'd)

TABLE OF CONTENTS (cont'd)

LIST OF FIGURES

LIST OF FIGURES (Cont'd)

LIST OF FIGURES (Cont'd)

LIST OF FIGURES (Cont'd)

LIST OF FIGURES (Cont'd)

LIST OF FIGURES (Cont'd)

LIST OF FIGURES (Cont'd)

LIST OF FIGURES (Cont'd)

LIST OF FIGURES (Cont'd)

LIST OF FIGURES (Cont'd)

LIST OF FIGURES (Cont'd)

LIST OF FIGURES (Cont'd)

LIST OF FIGURES (Cont'd)

LIST OF FIGURES (Cont'd)

LIST OF FIGURES (Cont'd)

LIST OF TABLES

LIST OF TABLES (Cont'd)

LIST OF TABLES (Cont'd)

LIST OF TABLES (Cont'd)

LIST OF TABLES (Cont'd)

I. INTRODUCTION

The Nuclear Engine for Rocket Vehicle Application (NERVA) program is administered by the Space Nuclear Propulsion Office, a joint office of the US Atomic Energy Commission and the National Aeronautics and Space Administration. Aerojet-General Corporation is the prime contractor for the engine system and Westinghouse Electric Company is the principal subcontractor responsible for the nuclear subsystem.

Since 1963 the Nuclear Aerospace Research Facility at the Fort Worth Division of General Dynamics has, under contract to SNPO-C, been conducting a series of tests on NERVA components and materials. The results of these tests may be found in GD reports FZK-170, Volumes 1 through 9 (1963); FZK-181 (1964); FZK-184, Volumes 1 through 6 (1964-65); FZK-263, Volumes 1, 2, and 3 (1965); FZK-310, Volumes 1 and 2 (1966-67); and FZK-342, Volumes 1, 2, and 3 (1968).

GTR Test 21, the latest in the series of tests, was conducted in accordance with specifications in AGC report RN-S-0411, Test Specifications for Irradiation Test GTR 21, and Modifications 1 and 2 thereto. This document, Volume 4 of the GTR-21 series, reports on the response of cryogenic and high-temperature structural materials to radiation. Part I describes the Cryogenic Structural Materials Test (37R018) and Part II describes the High-

Temperature Structural-Materials Test (37R017). All mechanical-properties data are presented in this report; the results of the metallographic studies will be reported in Volume 5.

The dosimetry procedures and results, along with the reactor log, are given in Appendix A. Supplementary data on the specimens are presented in Appendices B, C, and D, and a description of the GTR Radiation Effects Testing Facility is given in Appendix E.

II. DATA SUMMARY

2.1 Cryogenic Structural Materials (37R018)

Thirty-six specimens of Aluminum 7039 and eight specimens of Hastelloy X were irradiated and subsequently tensile-tested in liquid nitrogen. Controls (unirradiated specimens) were also tested in LN_2. Except for some of the irradiated aluminum specimens which were annealed at either 440° or $540^{\circ}R$ prior to testing, the specimens were submerged in LN_2 from the beginning of the irradiation through completion of the tensile tests.

2.1.1 Tensile Data for Aluminum 7039

Specimens were fabricated of Aluminum 7039-T61 from both the parent and as-welded materials and of Aluminum 7039-T64 from the parent material and material welded and treated to T61. Specimen configurations were round-unnotched and flat-notched.

The averaged test data for the round specimens, along with neutron fluences and test conditions, are given in Table 2-1; Table 2-2 gives the averaged data for the flat specimens. The standard deviation and the percent standard deviation of the averages are included. The data for the individual specimens are given in Section 4.2.

It should be noted that the thermal-neutron fluence was essentially constant for each group of two or three specimens. However, the fast-neutron fluence to which each specimen was

Table 2-1

AVERAGED TEST DATA FOR ROUND – UNNOTCHED SPECIMENS OF ALUMINUM 7039 AND HASTELLOY X IRRADIATED AND/OR TESTED AT 140°R

Specimen configuration: round-unnotched - Dwg. No. AGC 1134298-1. Data to be used for material evaluation only. Do not use for design.

Material	Specimen Number	Condition	Anneal Time and Temp	Stat Data[a]	0.2% Offset Yield Stress (ksi)	Strain @ 0.2% Yield Point (in./in.)	Max Stress (ksi)	Plastic Strain @ Max Stress (in./in.)	Frac Stress (ksi)	Plastic Strain @ Frac Stress (in./in.)	% Elongation		% Area Reduct (Bench)	Neutron Fluence (10^{16} n/cm^2)	
											Bench	Chart		Fast[b]	Thermal[c]
Aluminum 7039-T61, Parent	A 01,02, 03	Control	None	Avg	57.1	0.0191	77.7	0.133	70.7	0.161	16.0	16.2	31.6		
				SD	0.50	0.0005	0.23	0.015	0.85	0.012	1.43	1.21	2.55		
				% SD	0.88	3.14	0.30	10.9	1.20	7.61	8.95	7.46	8.08		
	A 05,06,	Irrad	None	Avg	63.1	0.021	78.9	0.107	73.1	0.140	13.9	14.0	34.1	8.9	2.4
				SD	0.07	0.0005	0.424	0.0009	1.06	0.0005	0.71	0.07	2.12		
				% SD	0.11	2.41	0.54	0.86	1.45	0.36	5.09	0.51	6.22		
	A 07,08, 09	Irrad	1 hour at 440°R	Avg	60.0	0.020	78.9	0.111	71.6	0.150	15.5	15.1	31.0	10.3	2.0
				SD	0.49	0.0004	0.12	0.002	0.0	0.004	0.61	0.40	0.46		
				% SD	0.82	1.88	0.15	1.73	0.0	2.87	3.92	2.68	1.48		
	A 10,11, 12	Irrad	1 hour at 540° R	Avg	59.1	0.020	78.3	0.115	71.5	0.151	15.6	15.1	31.5	11.0	2.1
				SD	0.10	0.0	0.10	0.004	0.0	0.002	0.49	0.21	0.49		
				% SD	0.17	0.0	0.13	3.66	0.0	1.24	3.17	1.38	1.57		
Aluminum 7039-T61, as Welded	AW 01,02, 03	Control	None	Avg	31.7	0.0134	60.2	0.121	59.9	0.122	13.0	12.2	29.6		
				SD	0.76	0.0006	0.265	0.015	0.42	0.015	1.50	1.47	1.42		
				% SD	2.38	4.66	0.44	12.1	0.70	12.1	11.6	12.1	4.80		
	AW 04,05, 06	Irrad	None	Avg	41.3	0.015	58.0	0.108	57.6	0.113	11.7	11.3	32.4	9.9	2.3
				SD	1.27	0.0005	1.02	0.004	0.99	0.004	0.93	0.40	2.61		
				% SD	3.06	3.34	1.76	3.42	1.71	3.62	7.96	3.59	8.04		
	AW 07,08, 09	Irrad	1 hour at 440° R	Avg	36.1	0.0144	58.7	0.1161	57.4	0.120	11.8	12.0	28.8	10.9	2.1
				SD	1.72	0.0008	1.85	0.0010	2.50	0.010	0.25	0.99	3.16		
				% SD	4.77	5.26	3.15	8.37	4.36	7.97	2.14	8.21	11.0		
	AW 10,11, 12	Irrad	1 hour at 540° R	Avg	31.2	0.0132	57.1	0.125	56.0	0.121	12.3	12.2	32.6	11.3	2.2
				SD	0.78	0.0003	1.25	0.017	1.42	0.015	1.38	1.53	0.68		
				% SD	2.50	2.27	2.19	13.5	2.53	12.6	11.2	12.6	2.08		

[a] Average, standard deviation, and percent standard deviation

[b] Fast - E >1.0 MeV

[c] Thermal - E < 0.48 eV

Table 2-1 (Cont'd)

Material	Specimen Number	Condition	Stat Data[a]	Plastic & Elastic Strain @ Max Stress (in./in.)	Total Permanent Strain (in./in.)	Plastic & Elastic Strain @ Frac Stress (in./in.)	Modulus of Elasticity (10^6 psi)	Resiliency (in.-lb/in.^{3})	Plasticity (in.-lb/in.^{3})	Energy Absorption (in.-lb/in.^{3})	Hardness, Rockwell E Scale: As Received	Hardness, Rockwell E Scale: After Testing
Aluminum 7039-T61, Parent	A 01,02, 03	Control	Avg	0.141	0.162	0.183	3.4	601	9,339	12,510	97.9	96.6
			SD	0.002	0.012	0.012	0.058	22.1	136.3	877	0.36	0.20
			% SD	1.10	7.61	6.42	1.72	3.67	1.46	7.01	0.37	0.21
	A 04,05, 06	Irrad	Avg	0.1308	0.1397	0.161	3.35	709	8,845	11,219	98.0	96.4
			SD	0.0005	0.0005	0.0003	0.07	19.8	96.9	34.7	0.40	0.64
			% SD	0.38	0.36	0.18	2.11	2.79	1.10	0.31	0.41	0.66
	A 07,08, 09	Irrad	Avg	0.1345	0.1504	0.172	3.33	646	9,030	11,917	98.0	95.7
			SD	0.003	0.004	0.005	0.12	6.35	170.7	347.8	0.10	0.40
			% SD	1.94	2.87	2.87	3.46	0.98	1.89	2.92	0.10	0.42
	A 10,11, 12	Irrad	Avg	0.1383	0.1508	0.172	3.4	640	9,253	11,831	99.4	99
			SD	0.004	0.002	0.002	0.0	1.53	319.5	137.3	0.12	0.36
			% SD	3.01	1.24	1.06	0.0	0.24	3.45	1.16	0.12	0.36
Aluminum 7039-T61, as Welded	AW 01,02, 03	Control	Avg	0.1430	0.1221	0.144	2.8	237	6,841	6,902	97.7	96.6
			SD	0.014	0.015	0.014	0.15	13.5	791	798.8	0.31	0.17
			% SD	9.76	12.1	9.74	5.52	5.71	11.56	11.6	0.31	0.18
	AW 04,05, 06	Irrad	Avg	0.1267	0.1125	0.131	3.1	340	6,207	6,448	97.2	95.9
			SD	0.003	0.004	0.004	0.006	16.9	148.6	122.5	0.31	0.30
			% SD	2.72	3.62	2.87	1.84	4.97	2.39	1.90	0.31	0.31
	AW 07,08, 09	Irrad	Avg	0.1362	0.1197	0.139	2.9	290	6,545	6,729	97.2	96.1
			SD	0.009	0.009	0.009	0.116	24.8	712.9	679.4	0.46	0.65
			% SD	6.90	7.97	6.68	3.94	8.54	10.89	10.10	0.47	0.68
	AW 10,11, 12	Irrad	Avg	0.1389	0.121	0.141	2.8	233	6,365	6,509	97.2	95.2
			SD	0.016	0.015	0.016	0.10	8.72	1,011	993	0.25	0.82
			% SD	11.8	12.6	11.4	3.57	3.74	15.9	15.3	0.26	0.86

Table 2-1 (Cont'd)

Specimen configuration: round-unnotched - Dwg. No. AGC 1134298-1. Data to be used for material evaluation only. Do not use for design.

Material	Specimen Number	Condition	Stat Data[a]	0.2% Offset Yield Stress (ksi)	Strain @ 0.2% Yield Point (in./in.)	Max Stress (ksi)	Plastic Strain @ Max Stress (in./in.)	Frac Stress (ksi)	Plastic Strain @ Frac Stress (in./in.)	% Elongation Bench	% Elongation Chart	% Area Reduct (Bench)	Neutron Fluence (10^{16} n/cm2) Fast[b]	Neutron Fluence (10^{16} n/cm2) Thermal[c]
Aluminum 7039-T64, Welded & Treated to T61	BW 01,02, 03	Control	Avg	30.3	0.013	57.4	0.074	55.3	0.084	8.7	8.4	33.6		
			SD	2.01	0.001	1.19	0.007	3.46	0.014	1.64	1.33	2.01		
			% SD	6.63	8.47	2.08	9.36	6.26	16.13	18.83	15.8	6.25		
	BW 04,05, 06	Irrad	Avg	43.3	0.016	59.6	0.067	58.4	0.071	7.2	7.0	30.2	10.3	2.4
			SD	1.72	0.001	0.51	0.002	0.32	0.004	0.51	0.42	3.76		
			% SD	3.98	6.61	0.86	2.28	0.55	6.12	7.16	5.92	12.4		
Aluminum 7039-T64, Parent	B 01,02, 03	Control	Avg	67.8	0.0217	84.8	0.128	80.9	0.141	13.9	14.0	28.7		
			SD	0.058	0.0003	0.17	0.012	0.80	0.007	1.04	0.68	2.12		
			% SD	0.09	1.31	0.20	9.26	0.99	4.84	7.48	4.85	7.38		
	B 04,05, 06	Irrad	Avg	73.4	0.023	85.7	0.103	81.1	0.133	12.8	13.3	23	9.9	2.5
			SD	0.62	0.0002	0.31	0.003	0.35	0.002	0.30	0.17	1.01		
			% SD	0.85	0.86	0.36	2.62	0.43	1.57	2.38	1.31	4.38		
Hastelloy X, Parent	H 01,02, 03,04	Control	Avg	67.4	0.016	124.3	0.217	124.3	0.217	21.6	21.7	22.7		
			SD	0.47	0.0005	4.21	0.023	4.21	0.023	2.36	2.3	2.62		
			% SD	0.69	2.91	3.39	10.4	3.39	10.4	10.9	10.6	11.5		
	H 05,06, 07,08	Irrad	Avg	89.7	0.019	128.6	0.168	128.6	0.168	16.7	16.8	20.6	11.3	1.8
			SD	2.68	0.0008	2.73	0.011	2.73	0.011	0.94	1.11	1.79		
			% SD	2.99	4.05	2.12	6.53	2.12	6.53	5.60	6.61	8.71		
Hastelloy X, Weldment	HW 01,02, 03,04	Control	Avg	70.2	0.0168	125.7	0.171	125.2	0.165	16.4	16.6	21.1		
			SD	0.39	0.0006	1.20	0.016	1.65	0.008	0.96	0.87	0.63		
			% SD	0.55	3.53	0.96	9.15	1.31	5.13	5.84	5.26	2.97		
	HW 05,06, 07,08	Irrad	Avg	91.4	0.0197	129.9	0.126	129.6	0.129	13.1	12.9	18.4	11.5	1.7
			SD	2.33	0.0003	0.90	0.007	1.08	0.008	0.88	0.76	1.16		
			% SD	2.55	1.34	0.69	5.65	0.83	6.18	6.71	5.91	6.27		

[a] Average, standard deviation, and percent standard deviation

[b] Fast - E > 1.0 MeV

[c] Thermal - E < 0.48 eV

Table 2-1 (Cont'd)

Material	Specimen Number	Condition	Stat Data[a]	Plastic & Elastic Strain @ Max Stress (in./in.)	Total Permanent Strain (in./in.)	Plastic & Elastic Strain @ Frac Stress (in./in.)	Modulus of Elasticity (10^6 psi)	Resiliency (in.-lb/in.^{3})	Plasticity (in.-lb/in.^{3})	Energy Absorption (in.-lb/in.^{3})	Hardness, Rockwell B Scale: As Received	Hardness, Rockwell B Scale: After Testing
7039-T64, Welded & Treated to T61	BW 01,02, 03	Control	Avg	0.0932	0.086	0.104	2.9	214	4,556	4,459	74.4	71
			SD	0.007	0.012	0.014	0.10	30.4	1,004	203	0.62	0.71
			% SD	7.94	14.2	13.6	3.45	14.2	22.0	4.55	0.84	1.00
	BW 04,05, 06	Irrad	Avg	0.084	0.071	0.089	3.1	383	4,113	4,434	73.5	70.7
			SD	0.004	0.004	0.004	0.153	37.1	221.6	155.5	0.26	0.90
			% SD	4.19	6.12	4.00	4.88	9.70	5.39	3.51	0.36	1.27
Aluminum 7039-T64, Parent	B 01,02, 03	Control	Avg	0.136	0.140	0.164	3.4	783	9,933	12,250	76.3	73.4
			SD	0.002	0.007	0.007	0.06	6.43	184.8	623.6	1.04	2.08
			% SD	1.60	4.84	4.44	1.68	0.82	1.86	5.09	1.37	2.84
	B 04,05, 06	Irrad	Avg	0.128	0.133	0.156	3.4	922	9,490	11,868	77.2	73.4
			SD	0.003	0.002	0.002	0.06	17.0	231.0	235.2	0.15	1.07
			% SD	2.13	1.57	1.41	1.68	1.84	2.43	1.98	0.20	1.46
Hastelloy X, Parent	H 01,02, 03,04	Control	Avg	0.244	0.217	0.244	4.7	595	24,902	24,902	88.9	89.1
			SD	0.024	0.023	0.024	0.17	17.4	3,289	3,289	0.90	1.73
			% SD	9.71	10.4	9.71	3.61	2.94	13.2	13.2	1.02	1.94
	H 05,06, 07,08	Irrad	Avg	0.193	0.168	0.193	5.3	936	21,028	21,028	88.4	92.8
			SD	0.011	0.011	0.011	0.15	53.4	1,178	1,178	1.05	1.21
			% SD	5.78	6.54	5.78	2.84	5.71	5.60	5.60	1.19	1.31
Hastelloy X, Weldment	HW 01,02, 03,04	Control	Avg	0.191	0.165	0.192	4.75	643	19,327	19,381	87.7	88.0
			SD	0.009	0.008	0.009	0.21	25.2	1,157	1,136	0.52	1.56
			% SD	4.76	5.13	4.65	4.38	3.91	5.99	5.87	0.59	1.77
	HW 05,06, 07,08	Irrad	Avg	0.151	0.129	0.154	5.2	978	16,296	16,693	87.3	92.0
			SD	0.008	0.008	0.009	0.10	28.4	790	1,002	0.12	0.48
			% SD	5.01	6.18	5.60	1.85	2.90	4.85	6.01	0.13	0.52

Table 2-2

AVERAGED TEST DATA FOR FLAT-NOTCHED SPECIMENS OF ALUMINUM 7039 IRRADIATED AND/OR TESTED AT 140°R

Specimen configuration: Flat-notched - Dwg. No. AGC 1134350-3. Data to be used for material evaluation only. Do not use for design.

Material	Specimen Number	Condition	Stat Data[a]	Ultimate Stress (ksi)	Rockwell Hardness[b] As Received	Rockwell Hardness[b] After Testing	Neutron Fluence (10^{17} n/cm^2) Fast[c]	Neutron Fluence (10^{17} n/cm^2) Thermal[d]
Aluminum 7039-T61, Parent	A 15,16,17	Control	Avg	60.0	99.1	99.1		
			SD	3.33	0.21	0.12		
			% SD	5.6	0.2	0.1		
	A 18,19,20	Irrad	Avg	65.7	98.7	99.0	2.2	0.24
			SD	3.81	0.53	0.36		
			% SD	5.8	0.5	0.4		
Aluminum 7039-T61, as Welded	AW 15,16,17	Control	Avg	44.7	98.5	99.2		
			SD	2.86	0.90	0.26		
			% SD	6.4	0.9	0.3		
	AW 18,19,21	Irrad	Avg	51.7	99.0	98.0	2.0	0.21
			SD	0.49	0.49	0.30		
			% SD	1.0	0.5	0.3		
Aluminum 7039-T64, Welded & Treated to T61	BW 11,12,13	Control	Avg	43.0	75.0	72.2		
			SD	2.38	0.61	0.55		
			% SD	5.5	0.8	0.8		
	BW 14,15,16	Irrad	Avg	52.3	73.8	72.5	1.5	0.20
			SD	2.30	0.81	0.36		
			% SD	4.4	1.1	0.5		
Aluminum 7039-T64, Parent	B 09,11,16	Control	Avg	65.3	76.9	74.8		
			SD	0.53	0.16	0.91		
			% SD	0.8	0.2	1.2		
	B 12,13,14	Irrad	Avg	70.6	76.0	74.7	1.6	0.22
			SD	3.01	0.55	0.56		
			% SD	4.3	0.7	0.8		

[a] Average, standard deviation, and percent standard deviation
[b] A and AW specimens are Rockwell E; BW and B specimens are Rockwell B

[c] Fast - E $>$1.0 MeV
[d] Thermal - E $<$0.48 eV

exposed was somewhat different, depending on the location in the specimen array. For convenience, an average value is given in the summary tables and the individual values are given in Section 4.2 along with the individual specimen data. The dosimetry procedures are discussed in Appendix A.

The tensile tests were performed with an Instron machine at a crosshead speed of 0.02 in./min, which corresponds to an average strain rate for the round specimens of 0.013 in./in./min in the plastic region and a nominal strain rate of 0.002 in./in./min in the elastic region. (The average strain rate in the plastic region is based on a uniform reduced section of 1.50 in. The nominal strain rate is based on data obtained in the axiality tests.) The specimen dimensions were determined by bench measurements both before and after testing.

2.1.2 Tensile Data for Hastelloy X

Specimens of Hastelloy X were fabricated in a round-unnotched configuration from both the parent material and weldments. The crosshead speed of the Instron tester was 0.02 in./min, giving an average strain rate in the plastic region of 0.013 in./in./min. Conditions included only irradiated and unirradiated specimens tested at LN_2 temperature (140°R). The averaged test data, along with standard deviations and percent standard deviations, are given in Table 2-1. The complete test data are given in Section 4.3.

2.1.3 Statistical Comparisons

For a given material and a given measured property, t-tests of significance were used to evaluate the observed difference between the average value of specimens tested under one set of conditions and those tested under a different set of conditions. A confidence interval of 90% ($\alpha = 0.10$) was used in all the t-tests. The standard deviation used to obtain the confidence interval was based on all those values for the particular property (regardless of test conditions) that had been obtained from specimens of the same configuration and material.

The results of the comparisons for each of the materials are summarized in Table 2-3. The effect of changing the test condition, such as comparing data from the irradiated specimens with data from the control specimens, is shown as a statistically significant increase (Incr) and decrease (Decr) or as being not significant (-). An X indicates that no comparison could be made for that property. It is important to note in using Table 2-3 that the first condition given, e.g., Control, is always the reference condition. Bar charts showing the magnitudes and ranges of the differences between conditions are given in Sections 4.2 and 4.3.

2.2 High-Temperature Structural Materials (37R017)

Round-unnotched and round-notched (also called combination) specimens of high-temperature structural materials were irradiated in the water at three different distances from the south face of

Table 2-3

STATISTICAL SIGNIFICANCE OF THE EFFECT OF TEST CONDITIONS ON ALUMINUM 7039 AND HASTELLOY X

Material	Specimen Data Compared[a]	Statistical Significance[b] ($\alpha = 0.10$): 0.2% Offset Yield Stress	Max Stress	Frac Stress	% Elongation: Bench	% Elongation: Chart	% Area Reduction (Bench)
Al 7039-T61, Parent	Control vs irradiated	Incr	Incr	Incr	Decr	Decr	-
	Control vs irradiated & anneal @ 440°R	Incr	Incr	-	-	Decr	-
	Control vs irradiated & anneal @ 540°R	Incr	Incr	-	-	Decr	-
	Irradiated vs irradiated & anneal @ 440°R	Decr	-	Decr	Incr	-	Decr
	Irradiated vs irradiated & anneal @ 540°R	Decr	Decr	Decr	Incr	-	-
	Irrad & anneal @ 440°R vs irrad & anneal @ 540°R	Decr	Decr	-	-	-	-
Al 7039-T61, as Welded	Control vs irradiated	Incr	Decr	-	-	-	-
	Control vs irradiated & anneal @ 440°R	Incr	-	Decr	-	-	-
	Control vs irradiated & anneal @ 540°R	-	Decr	Decr	-	-	-
	Irradiated vs irradiated & anneal @ 440°R	Decr	-	-	-	-	Decr
	Irradiated vs irradiated & anneal @ 540°R	Decr	-	-	-	-	-
	Irrad & anneal @ 440°R vs irrad & anneal @ 540°R	Decr	-	-	-	-	Incr
Al 7039-T64, Welded & Treated to T61	Control vs irradiated	Incr	Incr	-	-	-	-
Al 7039-T64, Parent	Control vs irradiated	Incr	Incr	-	-	-	Decr
Al 7039-T61, Parent[c]	Control vs irradiated	X	-	X	X	X	X
Al 7039-T61, as Welded[c]	Control vs irradiated	X	Incr	X	X	X	X
Hastelloy X, Parent	Control vs irradiated	Incr	-	-	Decr	Decr	-
Hastelloy X, Weldment	Control vs irradiated	Incr	Incr	Incr	Decr	Decr	Decr

[a]Comparison is always the second condition compared to the first condition.

[b]Incr, Significant increase
Decr, Significant decrease
-, No significant change
X, No comparison possible

[c]Flat tensile specimens; all others round specimens.

the reactor core to obtain three different levels of thermal-neutron fluence. There were 18 specimens of René 41, 37 of Waspaloy, and 54 of Inconel 718. Tensile tests were subsequently performed at elevated temperatures. Specimens of Waspaloy and Inconel 718 were also tested to stress rupture.

In the summary tables, the fast- and thermal-neutron fluences are given as average values. The individual fluences for each specimen are given in the main data tables of Section VI.

2.2.1 Tensile Data for René 41

Specimens of René 41 were tested in the Instron tester at $1660^{\circ}R$ at average strain rates in the plastic region of 0.0013, 0.013, and 0.13 in./in./min and at $1860^{\circ}R$ at 0.0013 in./in./min. (The nominal strain rates in the elastic region were 0.0002, 0.002, and 0.02 in./in./min.) The averaged test data are given in Table 2-4, along with the test conditions and the average neutron fluences. Data for the individual specimens are given in Section 6.2.

2.2.2 Tensile Data for Waspaloy

Specimens of Waspaloy were tested in the Instron tester at 1560°, 1660°, and $1860^{\circ}R$ at an average strain rate in the plastic region of 0.0013 in./in./min. One set of control specimens and one set of irradiated specimens were tested at $1660^{\circ}R$ and an average strain rate in the plastic region of 0.013 in./in./min. The averaged test data are given in Table 2-5. The complete test data are given in Section 6.3

2.2.3 Tensile Data for Inconel 718

Inconel 718 specimens with boron contents of 0.6, 37, and 46 parts per million (L, N, and C specimens, respectively) were irradiated. Test temperatures were from 1510° to 1660°R; the average strain rate in the plastic region was 0.0013 in./in./min for most specimens. The averaged test data are given in Table 2-6. The complete test data are given in Section 6.4.

2.2.4 Stress-Rupture Data for Waspaloy

Round-unnotched (W) and round-notched (WS) specimens of Waspaloy were tested with a Riehle Creep Rupture Testing Machine at temperatures of 1660° and 1860°R, respectively. At 1660°R the initial stress of 105 ksi was applied for 100 hours. If the specimen did not fail within the first 100 hours, the stress was increased by 5 ksi every hour until rupture. At 1860°R the initial stress of 70 ksi was applied for 23 hours. If the specimen did not fail within the first 23 hours, the stress was increased by 5 ksi every hour until rupture. None of the notched specimens failed at the notch. The averaged test data are given in Table 2-7. The data for the individual specimens are given in Section 6.5.

2.2.5 Stress-Rupture Data for Inconel 718

Round-unnotched (N and L) and round-notched (NS) specimens of Inconel 718 were tested to stress rupture. The unnotched specimens were tested at 1660°R with an initial stress of 75 ksi. The two unirradiated specimens, NS 02 and NS 07, were the only notched specimens of Inconel 718 which did not fail at the notch. These two specimens did not fail within 23 hours, so the stress was increased hourly by 5 ksi until rupture. The averaged test data are given in Table 2-8. The complete test data are given in Section 6.6.

2.2.6 Statistical Comparisons

T-tests of significance at the 90% confidence level were used to evaluate differences between results for the various test conditions. The results are summarized in Tables 2-9, 2-10, and 2-11 for the tensile specimens of the three materials. The format of these tables is the same as that of Table 2-3, and the calculational procedure was the same for all materials. Bar charts showing the magnitudes and ranges of the differences between conditions are given in Sections 6.2, 6.3, and 6.4.

The stress-rupture data were not compared by means of the t-test. The test condition (stress) was changed for several of the control specimens because they did not rupture within the specified time. In addition, the t-test may not be applicable, since there is an indication in the data of a non-normal distribution. However, an inspection of the data in Tables 2-7 and 2-8 shows that significant changes in properties did occur as a result of the irradiation. These data are presented graphically in Sections 6.5 and 6.6.

Table 2-4

AVERAGED TENSILE TEST DATA FOR RENÉ 41

Specimen configuration: round-unnotched - Dwg. No. AGC 1134298-1. Data to be used for material evaluation only. Do not use for design.

Specimen Number	Condition	Strain Rate (in./in./min)	Test Temp (°R)	Stat Data[a]	0.2% Offset Yield Stress (ksi)	Max Stress (ksi)	Frac Stress (ksi)	% Elongation		% Area Reduct (Bench)	Hardness, Rockwell C		Radiation Exposure Neutron Fluence (n/cm^2)	
								Bench	Chart		Pre-Test	Post-Test	E >1 MeV	E < 0.48 eV
R1 01,03, R2 07	Control	0.0013	1660	Avg	114.26	160.81	160.59	10.50	10.15	13.82	39.7	38.8		
				SD	2.49	3.59	3.60	0.60	0.62	0.87				
				% SD	2.18	2.23	2.24	5.76	6.06	6.31				
R1 04,05, 06	Irrad	0.0013	1660	Avg	114.89	146.96	146.96	6.33	5.84	14.62	37.7	37.1	5.00(15)	8.80(15)
				SD	2.75	9.32	9.32	1.08	0.58	2.13				
				% SD	2.39	6.34	6.34	17.1	9.93	14.6				
R1 13,14, 15	Irrad	0.0013	1660	Avg	115.24	142.08	141.13	5.46	4.16	10.07	38.7	35.5	7.80(16)	2.00(17)
				SD	2.50	4.92	5.31	0.48	0.25	3.63				
				% SD	2.17	3.46	3.76	8.73	6.05	36.0				
R1 16,17, 18	Irrad	0.0013	1660	Avg	115.82	138.10	135.88	4.70	3.59	9.82	38.9	37.0	1.04(18)	4.44(18)
				SD	0.85	4.49	4.85	0.31	0.28	2.74				
				% SD	0.73	3.25	3.57	6.52	7.76	27.87				
R2 22	Irrad	0.013	1660	Avg	119.24	146.54	146.39	8.19	3.64	17.88	38.6	38.9	1.02(18)	4.29(18)
R2 23,24	Irrad	0.13	1660	Avg	117.59	159.80	159.80	12.03	11.41	16.89	38.6	38.2	9.58(17)	4.00(18)
				SD	0.87	1.13	1.13	0.06	0.30	1.97				
				% SD	0.74	0.71	0.71	0.53	2.60	11.6				
R2 08,09, 26	Control	0.0013	1860	Avg	112.14	120.18	107.19	5.16	5.05	9.51	39.2	38.1		
				SD	0.24	0.86	5.92	1.51	1.80	1.29				
				% SD	0.21	0.71	5.52	29.3	35.6	13.6				
R2 10,11, 12	Irrad	0.0013	1860	Avg	116.10	119.44	112.44	1.94	1.65	5.61	38.2	37.2	5.23(15)	9.13(15)
				SD	2.06	3.57	9.34	0.08	1.21	2.91				
				% SD	1.77	2.99	8.31	4.22	73.1	52.0				
R2 19,20, 21	Irrad	0.0013	1860	Avg	114.95	116.69	111.19	1.73	1.01	6.41	39.3	37.9	6.53(16)	1.65(17)
				SD	1.41	1.87	3.90	0.32	0.54	2.73				
				% SD	1.23	1.61	3.51	18.2	53.8	42.6				

[a] Average, standard deviation, and percent standard deviation

Table 2-5

AVERAGED TENSILE TEST DATA FOR WASPALOY

Specimen configuration: round-unnotched - Dwg. No. AGC 1134298-1. Data to be used for material evaluation only. Do not use for design.

Specimen Number	Condition	Strain Rate (in./in./min)	Test Temp (^{o}R)	Stat Data[a]	0.2% Offset Yield Stress (ksi)	Max Stress (ksi)	Frac Stress (ksi)	% Elongation Bench	% Elongation Chart	% Area Reduct (Bench)	Hardness, Rockwell C Pre-Test	Hardness, Rockwell C Post-Test	Radiation Exposure Neutron Fluence (n/cm^2) E > 1 MeV	Radiation Exposure Neutron Fluence (n/cm^2) E < 0.48 eV
W 01,02, 03	Control	0.0013	1560	Avg	98.28	160.92	144.14	28.82	28.66	30.15	36.6	35.3		
				SD	0.98	2.93	8.13	3.32	2.97	4.28				
				% SD	0.99	1.82	5.64	11.5	10.4	14.2				
W 04,07, 10	Irrad	0.0013	1560	Avg	98.52	159.41	151.92	23.84	22.96	23.79	37.2	34.8	9.60(16)	2.50(17)
				SD	2.84	3.12	8.24	2.45	2.63	2.20				
				% SD	2.88	1.96	5.43	10.3	11.5	9.26				
W 12,13, 16	Control	0.0013	1660	Avg	98.97	137.92	114.56	24.44	24.60	33.02	36.7	35.3		
				SD	0.68	1.99	8.20	2.48	2.66	4.45				
				% SD	0.68	1.45	7.16	10.2	10.8	13.5				
W 17,18, 19	Irrad	0.0013	1660	Avg	99.27	139.27	129.11	18.13	18.16	21.32	36.6	34.9	4.92(15)	8.57(15)
				SD	1.54	1.23	3.64	2.11	2.26	2.42				
				% SD	1.55	0.88	2.82	11.6	12.5	11.3				
W 21,22	Irrad	0.0013	1660	Avg	98.85	135.36	126.90	17.17	16.64	20.24	37.2	34.8	1.04(17)	2.71(17)
				SD	1.59	4.04	2.86	1.64	1.53	1.41				
				% SD	1.61	2.99	2.25	9.55	9.22	6.95				
W 23,24, 26	Irrad	0.0013	1660	Avg	96.34	136.98	132.56	13.76	13.70	19.96	36.6	33.0	8.07(17)	3.40(18)
				SD	2.68	0.09	0.99	0.27	0.12	2.28				
				% SD	2.78	0.06	0.75	1.97	0.86	11.4				
W 67,68, 70	Control	0.13	1660	Avg	98.74	163.49	158.85	21.62	21.79	28.40	35.8	35.8		
				SD	0.59	1.85	3.23	0.58	0.34	2.16				
				% SD	0.60	1.13	2.03	2.69	1.54	7.62				

[a] Average, standard deviation, percent standard deviation

Table 2-5 (Cont'd)

Specimen Number	Condition	Strain Rate (in./in./min)	Test Temp (°R)	Stat Data[a]	0.2% Offset Yield Stress (ksi)	Max Stress (ksi)	Frac Stress (ksi)	% Elongation		% Area Reduct (Bench)	Hardness Rockwell C		Radiation Exposure Neutron Fluence (n/cm²)	
								Bench	Chart		Pre-Test	Post-Test	E > 1 MeV	E < 0.48 eV
W 44,45,46	Irrad	0.13	1660	Avg	90.25	161.34	158.41	20.23	19.24	27.78	35.8	35.5	1.30(17)	3.68(17)
				SD	9.45	0.76	3.44	4.65	5.38	1.82				
				% SD	10.47	0.47	2.16	23.0	28.0	6.55				
W 27,28,29	Control	0.0013	1860	Avg	82.65	85.48	52.16	19.78	20.40	23.10	35.9	34.2		
				SD	2.42	2.41	5.08	1.55	2.29	3.05				
				% SD	2.93	2.82	9.74	7.84	11.2	13.2				
W 30,31,32	Irrad	0.0013	1860	Avg	85.46	87.22	75.47	9.28	8.86	15.41	36.5	35.4	4.30(15)	7.83(15)
				SD	5.61	3.53	6.98	2.02	2.30	2.02				
				% SD	6.56	4.04	9.24	21.7	25.9	13.1				
W 34,36,37	Irrad	0.0013	1860	Avg	83 96	85.90	76.07	7.65	7.05	12.10	36.1	34.2	1.04(17)	2.70(17)
				SD	2.05	1.00	2.93	0.53	0.34	1.57				
				% SD	2.44	1.17	3.85	6.97	4.85	13.0				
W 39,40,43	Irrad	0.0013	1860	Avg	86.65	86.82	83.55	4.91	3.78	7.27	36.6	35.7	1.32(18)	5.82(18)
				SD	2.04	1.86	1.47	0.99	0.95	0.75				
				% SD	2.36	2.15	1.76	20.2	25.1	10.3				

Table 2-6

AVERAGED TENSILE TEST DATA FOR INCONEL 718

(L-0.6 ppm B; N-37 ppm B; C-46 ppm B)

Specimen configuration: round-unnotched - Dwg. No. AGC 1134298-1,-3,-5. Data to be used for material evaluation only. Do not use for design.

Specimen Number	Condition	Strain Rate (in./in./min)	Test Temp (°R)	Stat Data[a]	0.2% Offset Yield Stress (ksi)	Max Stress (ksi)	Frac Stress (ksi)	% Elongation Bench	% Elongation Chart	% Area Reduct (Bench)	Hardness, Rockwell C Pre-Test	Hardness, Rockwell C Post-Test	Radiation Exposure Neutron Fluence (n/cm^2) E > 1 MeV	Radiation Exposure Neutron Fluence (n/cm^2) E < 0.48 eV
N 08,10, 11	Control	0.0013	1510	Avg	141.49	161.01	157.40	12.32	11.23	20.96	43.0	41.5		
				SD	3.50	1.33	2.50	0.35	0.54	0.81				
				% SD	2.47	0.83	1.59	2.81	4.81	3.86				
N 12,13, 14	Irrad	0.0013	1510	Avg	142.11	162.08	157.51	10.01	8.76	17.95	42.8	41.4	3.65(15)	6.40(15)
				SD	5.30	2.94	1.85	0.77	1.26	2.61				
				% SD	3.73	1.81	1.17	7.64	14.4	14.6				
N 15,17, 19	Irrad	0.0013	1510	Avg	145.27	164.31	160.05	7.57	7.75	18.63	44.8	43.7	5.77(16)	1.36(17)
				SD	4.10	4.73	7.10	2.09	0.73	1.50				
				% SD	2.82	2.88	4.43	27.6	9.46	8.06				
N 20,21, 23	Irrad	0.0013	1510	Avg	146.70	165.35	161.21	6.80	6.88	16.80	43.9	43.1	6.49(17)	2.33(18)
				SD	2.96	3.82	6.11	1.45	0.55	3.08				
				% SD	2.02	2.31	3.79	21.3	7.92	18.4				
N 04,58	Control	0.0013	1585	Avg	141.36	155.03	152.96	7.28	6.09	15.67				
				SD	7.16	5.83	5.61	1.27	1.31	2.16				
				% SD	5.07	3.76	3.67	17.5	21.5	13.8				
N 05,06, 07	Irrad	0.0013	1585	Avg	139.30	153.32	151.51	5.02	4.18	12.98	43.8	42.3	5.97(16)	1.48(17)
				SD	2.04	0.45	0.36	0.36	0.58	2.64				
				% SD	1.46	0.30	0.23	7.13	13.8	20.3				
N 24,25, 26	Control	0.0013	1660	Avg	141.55	149.16	145.25	5.41	4.59	14.07	44.7	44.0		
				SD	3.50	3.18	2.30	0.61	0.87	1.74				
				% SD	2.47	2.13	1.59	11.2	19.0	12.3				
N 27,28, 29	Irrad	0.0013	1660	Avg	141.44	148.34	146.00	4.27	3.01	10.91	44.1	43.2	4.53(15)	8.00(15)
				SD	2.42	1.78	1.51	0.59	0.34	2.91				
				% SD	1.71	1.20	1.03	13.7	11.3	26.7				
N 30,31, 32	Irrad	0.0013	1660	Avg	137.41	143.91	140.82	3.42	1.99	9.31	44.1	42.3	7.40(16)	1.82(17)
				SD	0.27	1.03	1.77	0.27	0.13	3.01				
				% SD	0.19	0.72	1.26	7.81	6.62	32.3				

[a] Average, standard deviation, percent standard deviation

Table 2-6 (Cont'd)

Specimen Number	Condition	Strain Rate (in./in. /min	Test Temp (^oR)	Stat Data[a]	0.2% Offset Yield Stress (ksi)	Max Stress (ksi)	Frac Stress (ksi)	% Elongation		% Area Reduct (Bench)	Hardness, Rockwell C		Radiation Exposure Neutron Fluence (n/cm^2)	
								Bench	Chart		Pre-Test	Post-Test	E > 1 MeV	E < 0.48 eV
N 33,34, 35	Irrad	0.0013	1660	Avg	136.82	143.93	141.91	3.16	1.28	8.91	43.4	43.3	6.58(17)	2.47(18)
				SD	0.46	0.92	1.42	0.67	0.21	3.45				
				% SD	0.34	0.64	1.00	21.1	16.5	38.7				
N 36,37, 39	Control	0.13	1660	Avg	136.89	155.98	146.86	12.72	12.56	27.37	43.8	43.2		
				SD	5.63	5.65	0.86	0.24	0.76	1.50				
				% SD	4.11	3.62	0.59	1.90	6.02	5.46				
N 41,42, 43	Irrad	0.13	1660	Avg	141.70	157.72	153.58	9.44	8.19	23.09	44.4	43.6	8.33(16)	2.16(17)
				SD	1.48	1.88	2.26	0.48	0.26	1.72				
				% SD	1.04	1.19	1.47	5.12	3.12	7.46				
L Series 3 Specimens AGC Data	Control	0.002	1660	Avg	135.7	150.3			9.3[b]	13.7				
				SD	0.58	2.9			1.2	0.6				
				% SD	0.43	1.92			12.9	4.22				
L 01,02, 12	Irrad	0.0013	1660	Avg	144.56	151.33	146.80	3.01	2.58	12.68	44.5	44.2	7.33(16)	1.87(17)
				SD	3.01	2.48	0.25	0.64	0.55	2.56				
				% SD	2.08	1.64	0.17	21.3	21.1	20.2				
L 04,06, 07	Irrad	0.0013	1660	Avg	145.62	145.94	144.23	0.29	0.32	16.80	44.4	43.3	8.73(17)	3.66(18)
				SD	4.74	4.99	2.11	0.18	0.22	1.63				
				% SD	3.26	3.42	1.46	61.2	68.1	9.71				
C Series 2 Specimens AGC Data	Control	0.002	1660	Avg	131.00	145.0			9.0[b]	10.5				
				SD	2.83	4.2			1.4	2.4				
				% SD	2.16	2.9			15.7	22.9				
C 01,02, 04	Irrad	0.0013	1660	Avg	130.28	140.10	113.19	5.72	5.17	12.70	40.2	42.6	8.72(16)	2.29(17)
				SD	0.43	1.90	3.90	1.61	1.31	2.30				
				% SD	0.33	1.36	3.45	28.1	25.4	18.12				
C 05,08	Irrad	0.0013	1660	Avg	130.12	136.78	101.23	5.47	3.68	15.62	42.7	42.2	9.85(17)	4.20(18)
				SD	0.18	0.25	8.39	1.07	0.18	1.82				
					0.14	0.19	8.28	19.6	5.00	11.6				

[b] Elongation in 4 diameters

Table 2-7

AVERAGED STRESS-RUPTURE DATA FOR WASPALOY

Specimen configuration: round-unnotched (W) - AGC Dwg. 1134298-1
combination-notched (WS) - AGC Dwg. 1134453

Data to be used for material evaluation only. Do not use for design.

Specimen Number	Condition	Test Temp (°R)	Stress (ksi)	Stat Data[a]	Time to Failure (h)	% Elongation Bench	% Elongation Chart	% Area Reduct (Bench)	Radiation Exposure Neutron Fluence (n/cm^2) E > 1.0 MeV	E < 0.48 eV
W 48,50, 72	Control	1660	105-135	Avg	90.1	15.5	14.8	21.5		
				SD	25.2	2.6	1.8	3.8		
				% SD	27.9	16.7	11.9	17.8		
W 53,54, 56	Irrad	1660	105	Avg	70.4	7.6	7.2	12.6	3.40(15)	6.00(15)
				SD	6.6	0.4	0.2	0.7		
				% SD	9.3	4.6	2.8	5.6		
W 57,58, 60	Irrad	1660	105	Avg	64.6	8.2	8.0	13.4	5.80(16)	1.43(17)
				SD	13.8	0.8	0.6	0.2		
				% SD	21.4	9.7	7.4	1.1		
W 61,62, 63	Irrad	1660	105	Avg	56.0	6.2	5.7	11.9	6.05(17)	2.13(18)
				SD	13.0	1.0	1.0	2.4		
				% SD	23.2	16.1	18.2	19.9		
WS 01,02	Control	1860	70-80	Avg	24.7	30.0	24.0	29.0		
				SD	0.2	5.6	4.5	3.4		
				% SD	0.9	21.5	18.9	11.7		
WS 03,04	Irrad	1860	70	Avg	14.3	7.3	6.0	10.0	3.64(15)	6.28(15)
				SD	2.1	0.8	0.6	0.6		
				% SD	14.4	10.7	9.4	5.7		
WS 05,06	Irrad	1860	70	Avg	13.1	6.4	4.8	7.6	6.15(16)	1.56(17)
				SD	1.6	1.4	0.8	2.5		
				% SD	12.5	22.1	16.4	32.8		

[a] Average, standard deviation, percent standard deviation

Table 2-8

AVERAGED STRESS-RUPTURE DATA FOR INCONEL 718

(L-0.6 ppm B; N-37 ppm B)

Specimen configuration: round-unnotched (N) - AGC Dwg. 1134298-1
combination-notched (NS) - AGC Dwg. 1134453

Data to be used for material evaluation only. Do not use for design.

Specimen Number	Condition	Test Temp (°R)	Stress (ksi)	Stat Data[a]	Time to Failure (h)	% Elongation		% Area Reduct (Bench)	Radiation Exposure Neutron Fluence (n/cm^2)	
						Bench	Chart		E > 1.0 MeV	E < 0.48 eV
N 45,46, 57	Control	1660	110	Avg	58.7	5.9	5.3	14.5		
				SD	9.4	2.2	2.5	2.4		
				% SD	16.0	37.9	46.1	16.3		
N 47,48, 49	Irrad	1660	110	Avg	55.5	4.3	4.0	11.5	3.78(15)	6.40(15)
				SD	9.5	0.2	0.1	2.2		
				% SD	17.2	4.0	3.5	19.2		
N 50,51, 52	Irrad			Avg	36.1	2.2	1.3	10.1	4.28(16)	1.04(17)
				SD	6.4	0.2	0.3	1.1		
				% SD	17.8	6.8	26.6	10.8		
N 53,55, 56	Irrad	1660	110	Avg	11.1	1.3	0.3	7.1	6.52(17)	2.33(18)
				SD	2.6	0.1	0.2	1.6		
				% SD	23.3	4.3	45.8	21.9		
L 11,13	Irrad	1660	110	Avg	45.0	3.3	1.9	13.7	4.80(16)	1.16(17)
				SD	9.6	0.2	0.2	7.5		
				% SD	21.2	6.5	11.5	54.7		
NS 02,07	Control	1760	75-110	Avg	29.8	19.4	18.3	20.2		
				SD	0.1	10.3	10.5	8.4		
				% SD	0.2	53.2	57.5	41.8		
NS 03,04	Irrad	1760	75	Avg	23.9	1.4	0.4	-	3.80(15)	6.40(15)
				SD	3.7	0.3	0	-		
				% SD	15.4	20.2	0	-		
NS 05,06	Irrad	1760	75	Avg	1.4	0.9	0.1	-	6.23(16)	1.59(17)
				SD	0.8	0.1	0	-		
				% SD	57.6	8.3	0	-		

[a] Average, standard deviation, percent standard deviation

Table 2-9

STATISTICAL SIGNIFICANCE OF THE EFFECT OF TEST CONDITIONS ON RENÉ 41

Test Temp (°R)	Strain Rate (in./in./min.)	Specimen Data Compared[a]	Statistical Significance[b] (α = 0.10) 0.2% Offset Yield Stress	Max Stress	Frac Stress	% Elongation Bench	% Elongation Chart	% Area Reduction (Bench
1660	0.0013	Control vs low irradiation	-	Decr	Decr	Decr	Decr	-
		Control vs medium irradiation	-	Decr	Decr	Decr	Decr	Decr
		Control vs high irradiation	-	Decr	Decr	Decr	Decr	Decr
		Low irradiation vs medium irradiation	-	-	-	-	Decr	Decr
		Low irradiation vs high irradiation	-	Decr	Decr	Decr	Decr	Decr
		Medium irradiation vs high irradiation	-	-	-	-	-	-
1860	0.0013	Control vs low irradiation	Incr	-	-	Decr	Decr	Decr
		Control vs medium irradiation	Incr	-	-	Decr	Decr	-
		Low irradiation vs medium irradiation	-	-	-	-	-	-
1660	As Compared	0.0013 vs 0.013 in./in./min, high irradiation	-	-	-	X	-	Incr
		0.0013 vs 0.13 in./in./min, high irradiation	-	Incr	Incr	Incr	Incr	Incr
		0.013 vs 0.13 in./in./min, high irradiation	-	Incr	Incr	X	Incr	-

[a]Comparison is always the second condition compared to the first condition.

[b]Incr, Significant increase
Decr, Significant decrease
-, No significant change
X, No comparison possible

Table 2-10

STATISTICAL SIGNIFICANCE OF THE EFFECT OF TEST CONDITIONS ON WASPALOY

Test Temp (^oR)	Strain Rate (in./in./min.)	Specimen Data Compared[a]	Statistical Significance[b] ($\alpha = 0.10$) 0.2% Offset Yield Stress	Max Stress	Frac Stress	% Elongation Bench	% Elongation Chart	% Area Reduction (Bench)
1560	0.0013	Control vs medium irradiation	-	-	Incr	Decr	Decr	Decr
1660	0.0013	Control vs low irradiation	-	-	Incr	Decr	Decr	Decr
		Control vs medium irradiation	-	-	Incr	Decr	Decr	Decr
		Control vs high irradiation	-	-	Incr	Decr	Decr	Decr
		Low irradiation vs medium irradiation	-	Decr	-	-	-	-
		Low irradiation vs high irradiation	-	-	-	Decr	Decr	-
		Medium irradiation vs high irradiation	-	-	-	-	-	-
1660	0.13	Control vs medium irradiation	Decr	-	-	-	-	-
1860	0.0013	Control vs low irradiation	-	-	Incr	Decr	Decr	Decr
		Control vs medium irradiation	-	-	Incr	Decr	Decr	Decr
		Control vs high irradiation	-	-	Incr	Decr	Decr	Decr
		Low irradiation vs medium irradiation	-	-	-	-	-	-
		Low irradiation vs high irradiation	-	-	Incr	Decr	Decr	Decr
		Medium irradiation vs high irradiation	-	-	Incr	-	-	Decr
1660	As Compared	0.0013 vs 0.13 in./in./min, control	-	Incr	Incr	-	-	Decr
		0.0013 vs 0.13 in./in./min, medium irradiation	Decr	Incr	Incr	-	-	Incr

[a]Comparison is always the second condition compared to the first condition.

[b]Incr, Significant increase
Decr, Significant decrease
-, No significant change

Table 2-11

STATISTICAL SIGNIFICANCE OF THE EFFECT OF TEST CONDITIONS ON INCONEL 718

Material Code[a]	Test Temp (°R)	Strain Rate (in./in./min)	Specimen Data Compared[b]	Statistical Significance[c] ($\alpha = 0.10$): 0.2% Offset Yield Stress	Max Stress	Frac Stress	% Elongation: Bench	% Elongation: Chart	% Area Reduction (Bench)
L	1660	0.0013	Control vs medium irradiation	Incr	-	X	X	Decr	-
			Control vs high irradiation	Incr	-	X	X	Decr	-
			Medium irradiation vs high irradiation	-	Decr	-	Decr	Decr	Incr
N	1510	0.0013	Control vs low irradiation	-	-	-	Decr	Decr	-
			Control vs medium irradiation	-	-	-	Decr	Decr	-
			Control vs high irradiation	Incr	-	-	Decr	Decr	Decr
			Low irradiation vs medium irradiation	-	-	-	Decr	-	-
			Low irradiation vs high irradiation	-	-	-	Decr	Decr	-
			Medium irradiation vs high irradiation	-	-	-	-	-	-
N	1585	0.0013	Control vs medium irradiation	-	-	-	Decr	Decr	-
N	1660	0.0013	Control vs low irradiation	-	-	-	-	Decr	-
			Control vs medium irradiation	-	Decr	-	Decr	Decr	Decr
			Control vs high irradiation	Decr	Decr	-	Decr	Decr	Decr
			Low irradiation vs medium irradiation	-	Decr	Decr	-	-	-
			Low irradiation vs high irradiation	-	-	-	-	Decr	-
			Medium irradiation vs high irradiation	-	-	-	-	-	-
N	1660	0.13	Control vs medium irradiation	Incr	-	Incr	Decr	Decr	Decr
C	1660	0.0013	Control vs medium irradiation	-	-	X	X	Decr	-
			Control vs high irradiation	-	Decr	X	X	Decr	Incr
			Medium irradiation vs high irradiation	-	-	Decr	-	Decr	-
N	1660	As Compared	0.0013 vs 0.13 in./in./min, control	Decr	Incr	-	Incr	Incr	Incr
			0.0013 vs 0.13 in./in./min, medium irradiation	-	Incr	Incr	Incr	Incr	Incr

[a]L - 0.6 ppm boron
N - 37 ppm boron
C - 46 ppm boron

[b]Comparison is always the second condition compared to the first condition.

[c]Incr, Significant increase
Decr, Significant decrease
-, No significant change
X, No comparison possible

Table 2-11 (Cont'd)

Material Code[a]	Test Temp (°R)	Strain Rate (in./in./min)	Specimen Data Compared[b]	Statistical Significance[c] ($\alpha = 0.10$) 0.2% Offset Yield Stress	Max Stress	Frac Stress	% Elongation Bench	% Elongation Chart	% Area Reduction (Bench)
L-N	1660	0.0013	L vs N, control	Incr	-	X	X	Decr	-
			L vs N, medium irradiation	Decr	Decr	Decr	-	-	Decr
			L vs N, high irradiation	Decr	-	-	Incr	-	Decr
L-C	1660	0.0013	L vs C, control	-	Decr	X	X	-	-
			L vs C, medium irradiation	Decr	Decr	Decr	Incr	Incr	-
			L vs C, high irradiation	Decr	Decr	Decr	Incr	Incr	-
N-C	1660	0.0013	N vs C, control	Decr	-	X	X	Incr	Decr
			N vs C, medium irradiation	Decr	-	Decr	Incr	Incr	Incr
			N vs C, high irradiation	Decr	Decr	Decr	Incr	Incr	Incr

III. TEST PROGRAM FOR CRYOGENIC STRUCTURAL MATERIALS

The purpose of this experiment was to obtain information on the effects of reactor radiation and a cryogenic environment on the tensile properties of Aluminum 7039 and Hastelloy X. Specimens fabricated from the parent materials and weldments of the materials were irradiated and tested while submerged in LN_2; in addition, some irradiated specimens of Aluminum 7039 were annealed for a short period of time prior to testing in LN_2.

The test specimens were irradiated at the bottom of a dewar which contained apparatus for the electrical-resistivity experiment (Test 39R201) reported in Reference 1. For the irradiation, the Ground Test Reactor (GTR) was operated at power levels up to 7.2 MW for a total of 2310 MWh. The irradiation began on 13 October 1967 and ended on 3 November 1967. The reactor log is given in Appendix A.

Upon completion of the irradiation, the dewar was transferred to the Irradiated Materials Laboratory (IML) with the specimens still stored in LN_2. The specimens were subsequently tensile-tested to fracture while in LN_2. Except for those specimens selected for annealing studies, the materials were submerged in LN_2 from the start of the irradiation until completion of the tensile tests. (On 7 October the dewar was filled with LN_2 for a short time for checkout purposes. The dewar was again filled on 8 October and the specimens were maintained in LN_2 until completion of testing.)

3.1 Test Materials and Specimens

Information concerning the Aluminum 7039 and the Hastelloy X stock and the subsequent specimen processing was provided by AGC and is presented in Table 3-1. Chemical analyses of the materials are presented in Tables 3-2 and 3-3. Sixty specimens of Aluminum 7039 (24 control and 36 irradiated) and 16 of Hastelloy X (8 control and 8 irradiated) were tested.

Aluminum 7039 is a heat-treatable, weldable aluminum alloy with zinc and magnesium as the chief alloying constituents. It is presently available in two heat-treated tempers, T61 and T64, both of which were tested. In addition, weldments of the alloy were tested.

Hastelloy X is a nickel-base superalloy which has excellent weldability properties. Specimens of both the parent metal and weldments of this material were tested in this experiment.

The basic conditions and forms of the Aluminum 7039 and Hastelloy X test materials were:

Metal	Form	Conditions
Aluminum 7039-T61	Plate	1. Parent 2. As welded
Aluminum 7039-T64	Plate	1. Parent 2. Welded and treated to T61
Hastelloy X	Forging	1. Parent 2. Weldment

Test specimens of the Aluminum 7039 material were of two configurations - round-unnotched and flat-notched; these configurations

Table 3-1

DESCRIPTION OF ALUMINUM 7039 AND HASTELLOY X STOCK AND SPECIMEN PROCESSING[a]

Forged or Rolled Stock as Received						Specimen Processing				
Code	Material	Vendor	Form and Dimensions	Heat Treat	Specification	Parent/ Welded	Anneal	Age	Specification	Hardness
A	AA-7039	Kaiser Aluminum	Plate 1"x30"x48"	T-61 Temper	AGC 90181	Parent T-61	None	None	None	62/64 R_B
B	AA-7039	Kaiser Aluminum	Plate 1"x30"x48"	T-64 Temper	AGC 90181	Parent T-64	None	None	None	71-72 R_B
AW	AA-5039	Kaiser Aluminum	0.0625" Dia. Filler Wire	Not Applicable	AGC 44091-2B	Plate T-61 Welded AA5039 Filler	Naturally Aged 30+ Days at Room Temperature		None	--
BW	AA-5039	Kaiser Aluminum	0.0625" Dia. Filler Wire	Not Applicable	AGC 44091-2B	Plate T-64 Welded AA5039 Filler	Solution Annealed and Aged to T-61 per Kaiser Proprietary Process		None	--
H	Hastelloy X	Viking Forge and Steel Co.	Ring Forging 20" O.D. x 17" I.D. x 6"	Annealed at 2150°F	AGC 90056-2	Parent	Original by Forger	Simulated Braze Treatment	Not Applicable	82 R_B
HW	Hastelloy X	Union Carbide Stellite	0.045" Dia. Root Pass Wire 0.062" Dia. Filler Wire	Not Applicable	AGC 90058	Welded	Reannealed	Simulated Braze Treatment	Not Applicable	--

[a]Data provided by AGC

Table 3-2

CHEMICAL ANALYSIS OF ALUMINUM 7039[a]

Material		Element (% by weight)									
		Al	Zn	Mg	Mn	Cu	Fe	Si	Cr	Ti	Be
AA-7039	Plate T-61	Bal	3.53	2.33	0.28	0.02	0.15	0.11	0.16	0.15	-
	Plate T-64	Bal	3.50	2.50	0.18	0.02	0.12	0.09	0.17	0.15	-
AA-X5039	Spool Lot No. 2006 0.062" Dia. Filler	Bal	2.4	4.0	0.40	0.30	0.30	0.10	0.10	0.04	0.0008

[a]Data provided by AGC

Table 3-3

CHEMICAL ANALYSIS OF HASTELLOY X[a]

Material		Element (% by weight)														
		Ni	Mo	Cr	Fe	C	Mn	Si	Al	Ti	W	Cu	Co	P	S	B
Hastelloy X	Ring Heat 261-5-4001	Bal	8.96	21.53	17.53	0.10	0.58	0.27	0.12	0.02	0.54	0.02	1.55	0.002	0.003	0.0007
	Filler, Heat 260-5-2783	Bal	8.90	21.57	18.09	0.08	0.51	0.32	0.28	0.28	0.38	0.02	1.40	0.005	0.001	0.0004

[a]Data provided by AGC

correspond to AGC Drawings 1134298-1 and 1134350-3, shown in Figures 3-1 and 3-2, respectively. Figure 3-3 shows a typical specimen of each type.

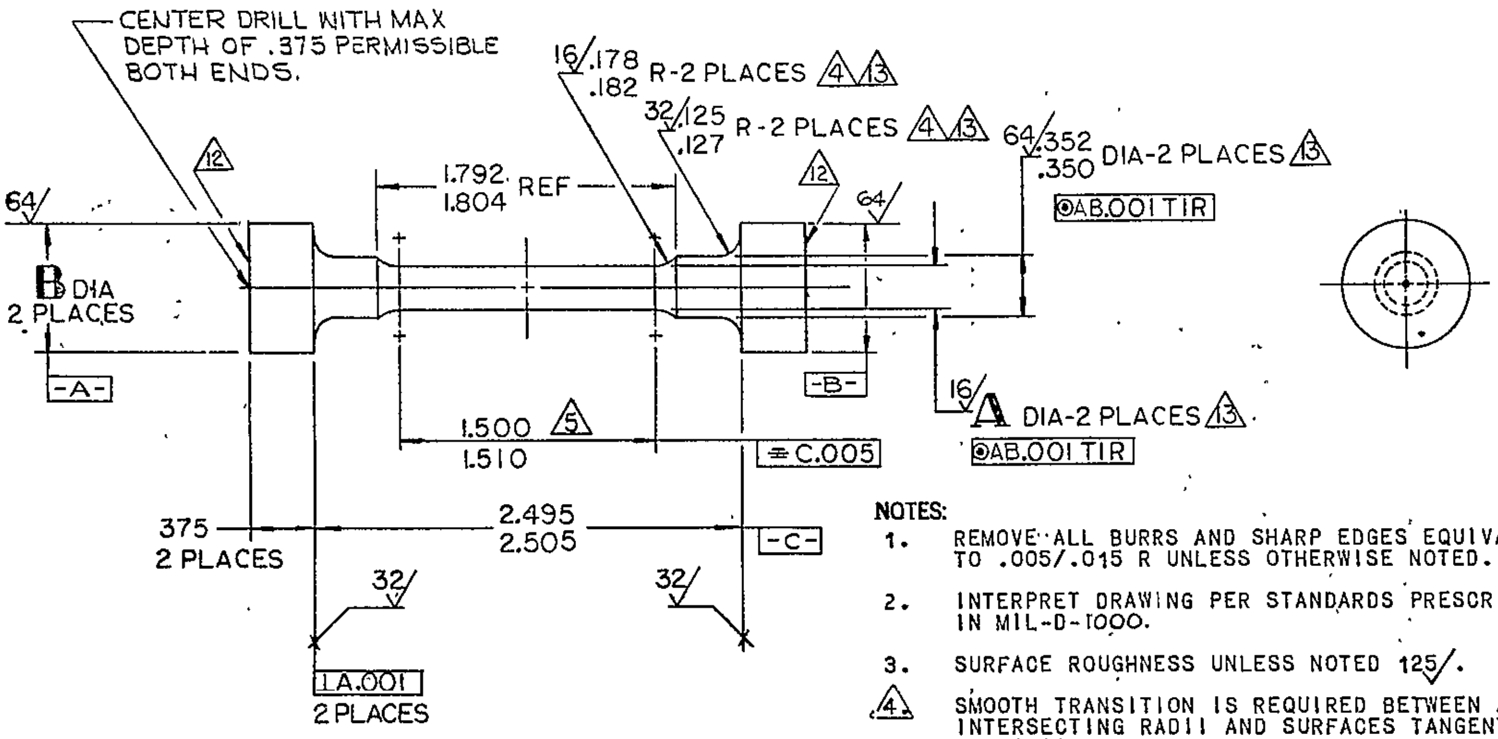
Test specimens of Hastelloy X were of the same configuration as the round-unnotched aluminum specimens.

Identification codes of the test specimens consisted of one or two alphabetic characters, which identified the material and condition, followed by two digits designating the specimen number. The specimen identification code was engraved on both ends of each specimen. Identification codes for the test materials are:

Material and Condition	Code
Aluminum 7039-T61, parent	A
Aluminum 7039-T61, as welded	AW
Aluminum 7039-T64, parent	B
Aluminum 7039-T64, welded and treated to T61	BW
Hastelloy X, parent	H
Hastelloy X, weldment	HW

3.2 Test Equipment and Instrumentation

Test equipment required for performing this experiment consisted of an irradiation dewar for maintaining the specimens in LN_2 during and after irradiation, a tensile test machine and associated components for testing the specimens in LN_2, and a fixture for annealing selected specimens at $440^{\circ}R$. Additional equipment



NOTES:

1. REMOVE ALL BURRS AND SHARP EDGES EQUIVALENT TO .005/.015 R UNLESS OTHERWISE NOTED.
2. INTERPRET DRAWING PER STANDARDS PRESCRIBED IN MIL-D-1000.
3. SURFACE ROUGHNESS UNLESS NOTED 125√.
4. △ SMOOTH TRANSITION IS REQUIRED BETWEEN ALL INTERSECTING RADII AND SURFACES TANGENT TO RADII.
5. △ NO DIA IN THIS SECTION MAY BE LESS THAN THAT MEASURED AT THE ℄ OF DATUM C.
6. △ MATERIAL TREATMENT, FINISH AND IDENTIFICATION TO BE DETERMINED BY COGNIZANT ENGINEER.
7. MARK PER ASD5215 M WITH 1134298 AND APPLICABLE DASH NO.
8. IF PART IS WELDED RADIOGRAPHIC INSPECT WELDS PER AGC-STD-1151. ACCEPT PER AGC-STD-4005 CL I.
9. PENETRANT INSPECT PER AGC-STD-3010. ACCEPT PER AGC-STD-4005 CL I.
10. CLEANLINESS PER AGC-STD-9007 LEVEL I.
11. PRESERVE & PACKAGE PER AGC-46387, CLASS I.
12. △ MARK PER ASD 5215 C OR D WITH CODE NO. PROVIDED BY COGNIZANT ENGINEER.
13. △ THESE DIMENSIONS TO BE INSPECTED AND RECORDED. INSPECTION RECORDS SHALL BE MARKED WITH PART SERIALIZATION NO.

DASH NO.	A DIA	B DIA
-1	.201/.199	.751/.749
-3	.201/.199	.626/.624
-5	.201/.199	.699/.701

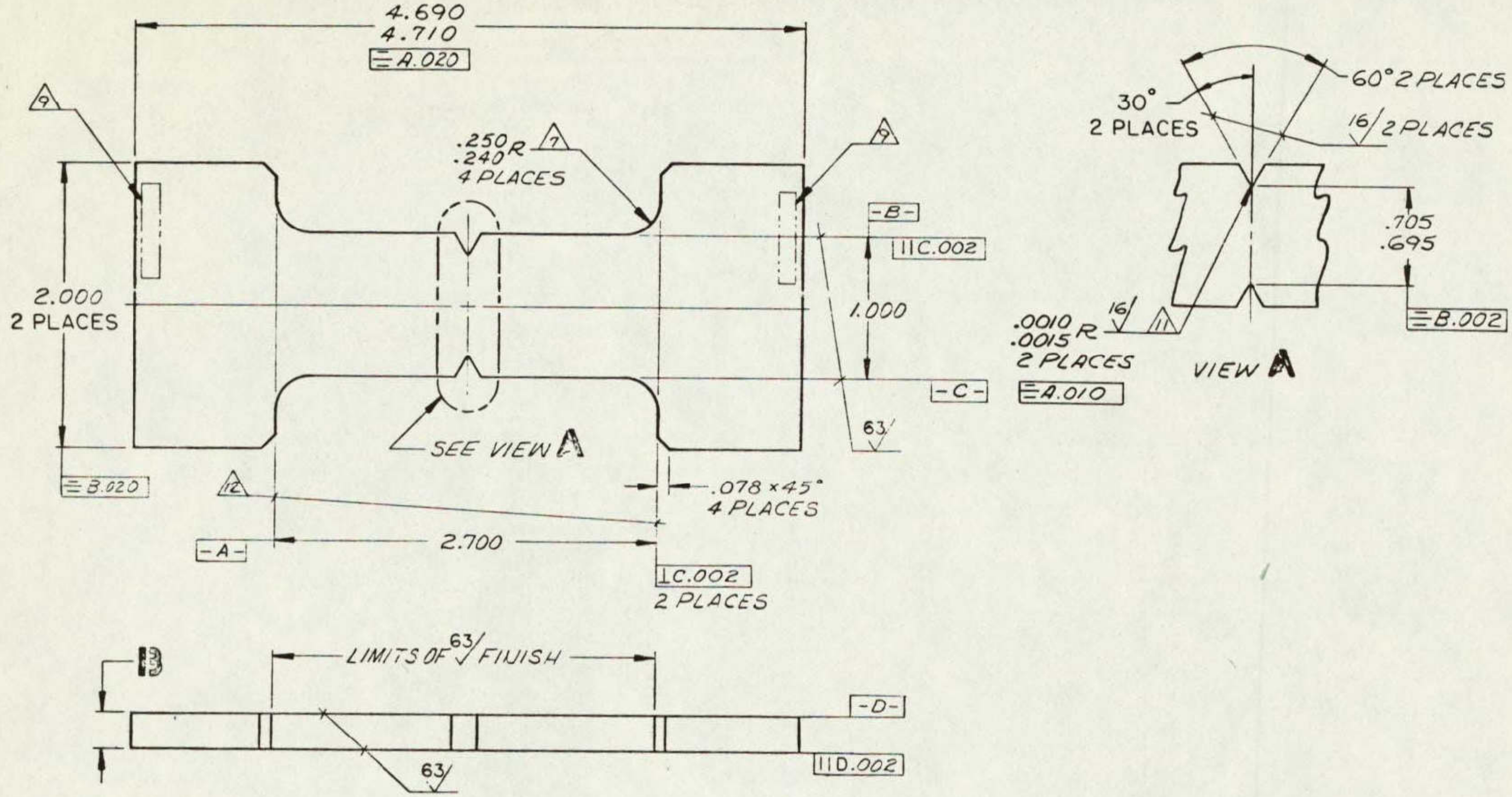
AEROJET-GENERAL CORPORATION
SACRAMENTO, CALIFORNIA
ROCKET ENGINE OPERATIONS - NUCLEAR

TITLE: SPECIMEN, TENSILE - BUTTON HEAD, ROUND

DWG SIZE	CODE IDENT NO.	DWG NO
D	05824	1134298

SCALE 2/1 RELEASE DATE SHEET

Figure 3-1 Configuration of Round, Button-Head Tensile Specimens (AGC Drawing 1134298)

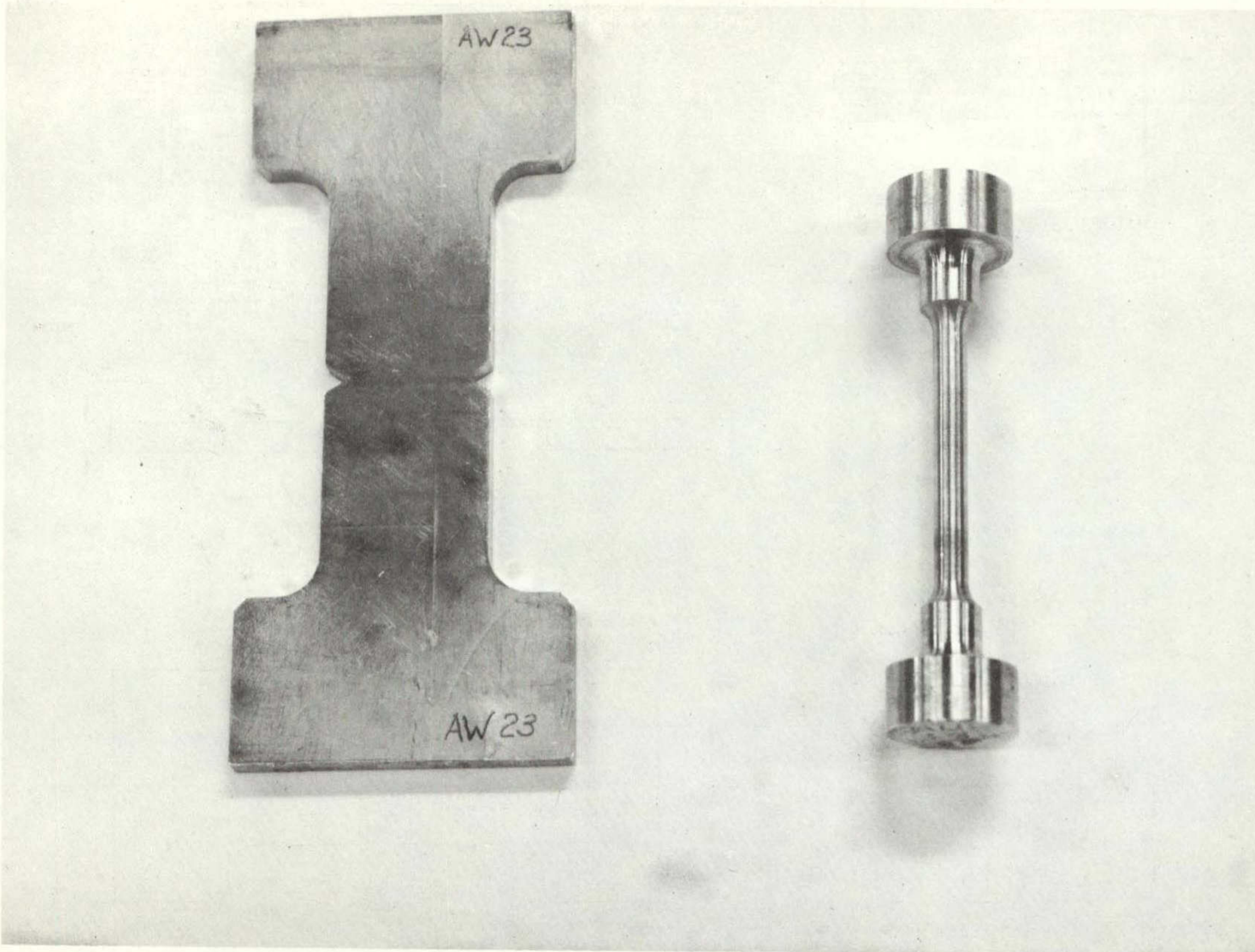


NOTES:

1. INTERPRET DRAWING PER STANDARDS PRESCRIBED IN MIL-D-1000.
2. REMOVE ALL BURRS AND SHARP EDGES EQUIVALENT TO .005-.015 R UNLESS OTHERWISE NOTED.
3. SURFACE ROUGHNESS 125 UNLESS OTHERWISE NOTED.
4. CLEANLINESS PER AGC-STD-9007 LEVEL I.
5. PRESERVE AND PACKAGE PER AGC-46387 CLASS I.
6. PENETRANT INSPECT PER AGC-STD-3010 METHOD B.
7. NO UNDERCUTS ALLOWED ON THIS RADIUS.
8. IF PART IS WELDED RADIOGRAPHIC INSPECT WELDS PER AGC-STD-1151. ACCEPT PER AGC-STD-9005 CL I.
9. MARK PER ASD 5215C WITH APPLICABLE SERIAL NO. PRIOR TO MACHINING. MARK AFTER MACHINING IF NECESSARY.
10. MATERIAL TO BE DETERMINED BY COGNIZANT ENGINEER.
11. THIS DIMENSION TO BE INSPECTED AND RECORDED.
12. THESE SURFACES TO BE COPLANAR WITHIN .002.

AEROJET-GENERAL CORPORATION, SACRAMENTO, CALIFORNIA — ROCKET ENGINE OPERATIONS - NUCLEAR			
TITLE: SPECIMEN, TENSILE-NOTCHED			
CODE IDENT NO. 05824	DWG SIZE D	DWG NO. 1134350	
SCALE 2/1	RELEASE DATE 8-28-67	SHEET	

Figure 3-2 Configuration of Flat, Notched Tensile Specimens (AGC Drawing 1134350)



NPC 26,767
31,9491

Figure 3-3 Typical Flat and Round Tensile Specimens included a microscope for determination of physical dimensions of the specimens before and after testing, a hardness tester, and a macrocamera for obtaining 10X photos of fractured specimens. More detailed descriptions of the test equipment are given below.

3.2.1 Irradiation Dewar

During the irradiation, the test specimens were submerged in liquid nitrogen contained in the irradiation dewar shown in Figure 3-4. The specimen rack with specimens installed is shown in Figure 3-5. The dewar was basically a rectangular aluminum container having a smaller inner container to hold the liquid nitrogen. No vacuum was used between the containers; cold-gas flow between the walls of the containers served as the thermal insulation.

The pressure and the liquid-nitrogen level inside the dewar were monitored continuously by means of a CEC pressure transducer and liquid-level system, respectively. One liquid-level probe with 12 resistors was used in conjunction with an indicator panel to monitor the liquid level. Another probe with 12 thermocouples was used in conjunction with a Bristol control unit to control liquid level.

3.2.2 Tensile Test Machine and Accessories

Tensile tests were performed with a Model TT-D split-console Instron Tensile Test Machine having a variable-range load capacity of 20,000 lb.

The dewar in which the specimens were immersed during tensile-testing is shown installed in the Instron strain frame in Figure 3-6.

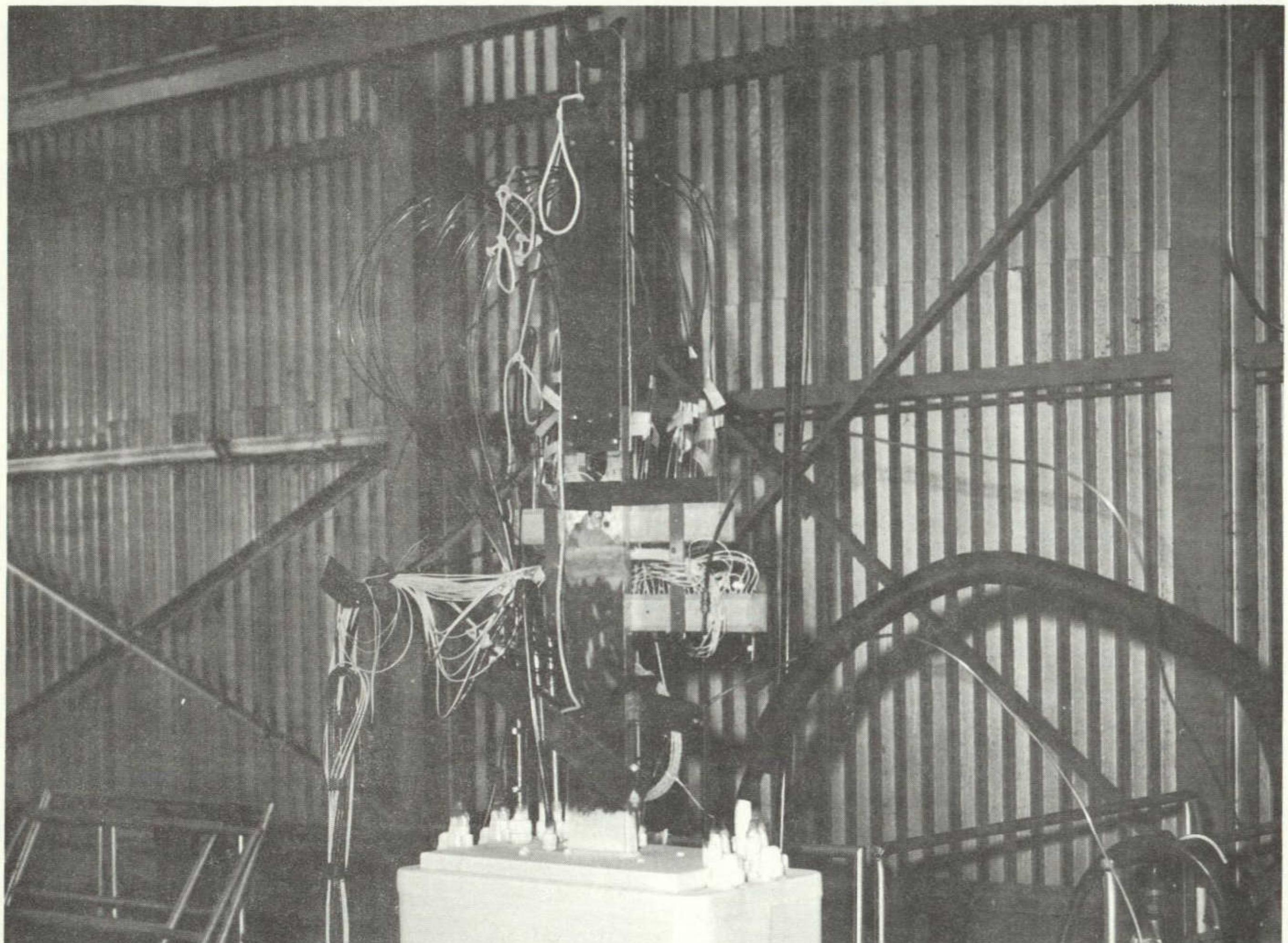
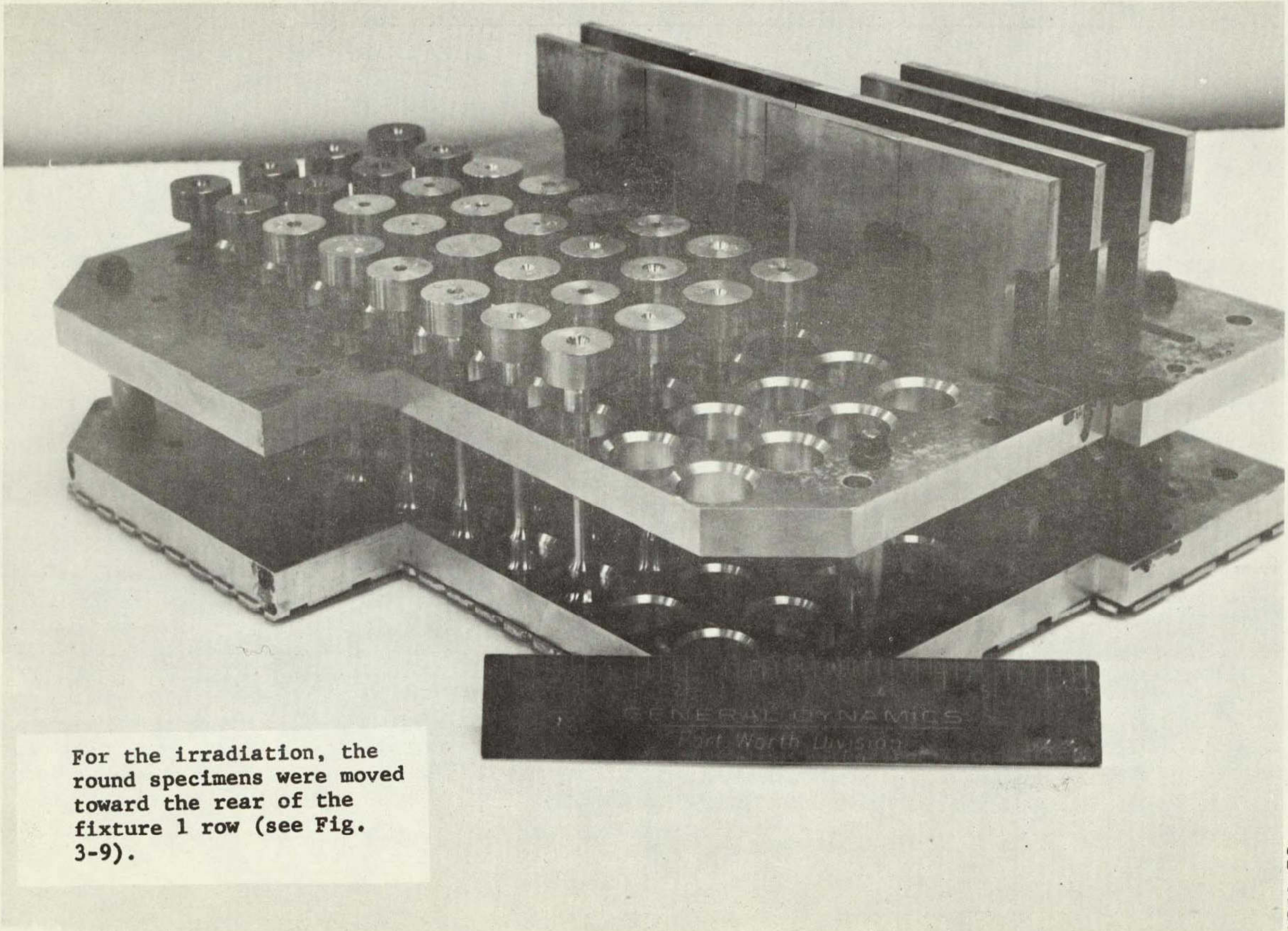


Figure 3-4 Liquid-Nitrogen Dewar with Hookup for the Electrical Resistivity Test



For the irradiation, the round specimens were moved toward the rear of the fixture 1 row (see Fig. 3-9).

Figure 3-5 Irradiation Rack for Cryogenic Specimens with Specimens Loaded

NPC 26,769
31-9220

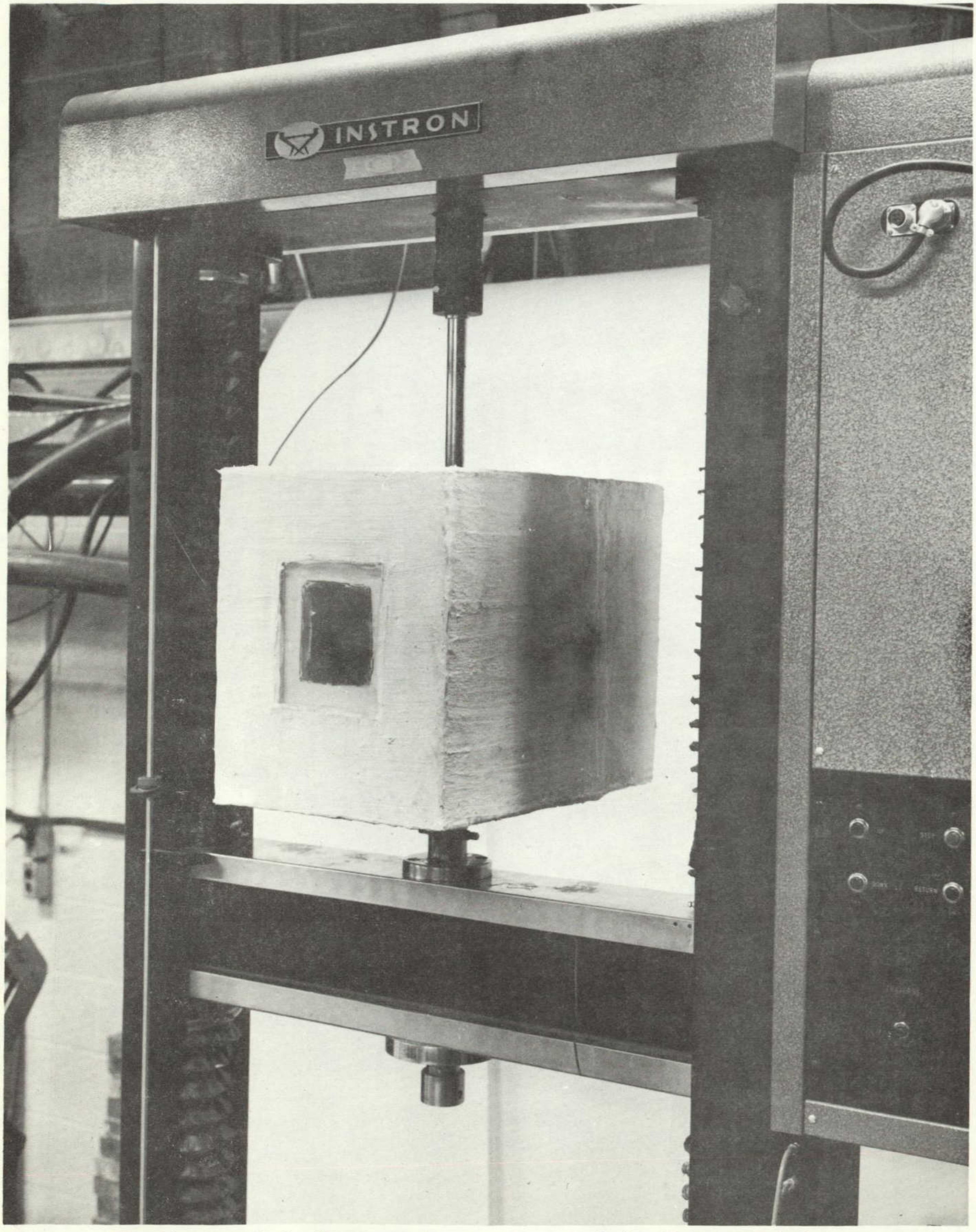


Figure 3-6 Instron Dewar Mounted in Test Position

The dewar was fabricated of urethane foam material; the inner and outer surfaces were coated with successive layers of RTV 102 silicone adhesive and fiberglass cloth, with the final layer of RTV 102.

Specimen grips used for testing of the cryogenic specimens are shown in Figure 3-7. Specimen grips S/N 9 and 10, fabricated of René 41, were used for all the round tensile specimens. Grips for the flat-notched specimens were grips which had been used previously; they were modified to accept the specimens involved in this test. Pull rods were fabricated of A-286 corrosion-resistant steel.

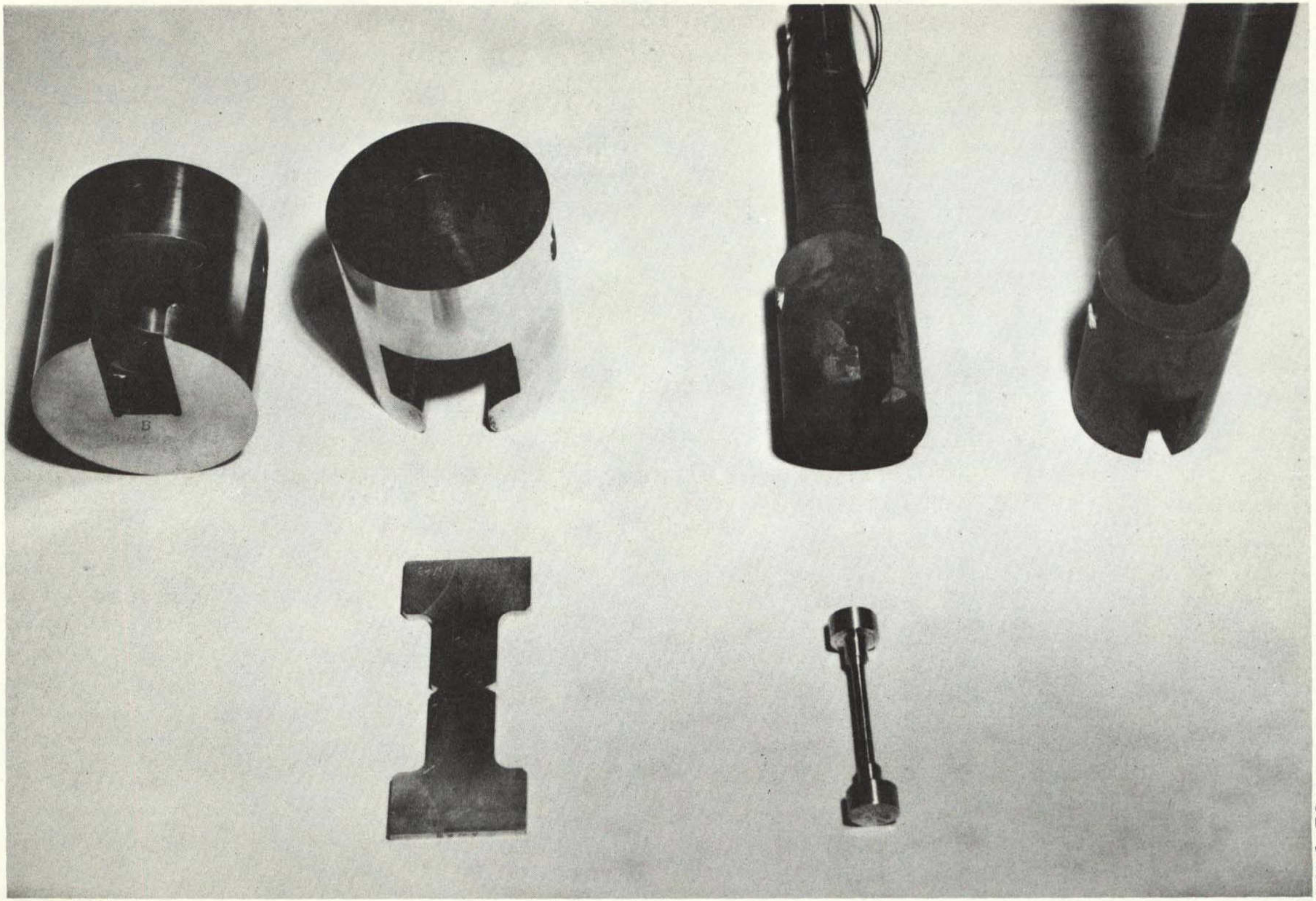
3.2.3 Annealing Fixture

The fixture for annealing test specimens at 440°R is shown in Figure 3-8. It consisted of a double-walled container having small holes in the inner wall. Cold nitrogen gas supplied at a controlled rate between the chamber walls flowed over the specimens, which were suspended in the wire basket within the container. A dummy specimen instrumented with a thermocouple was used to monitor temperatures during annealing.

3.3 Test Procedures

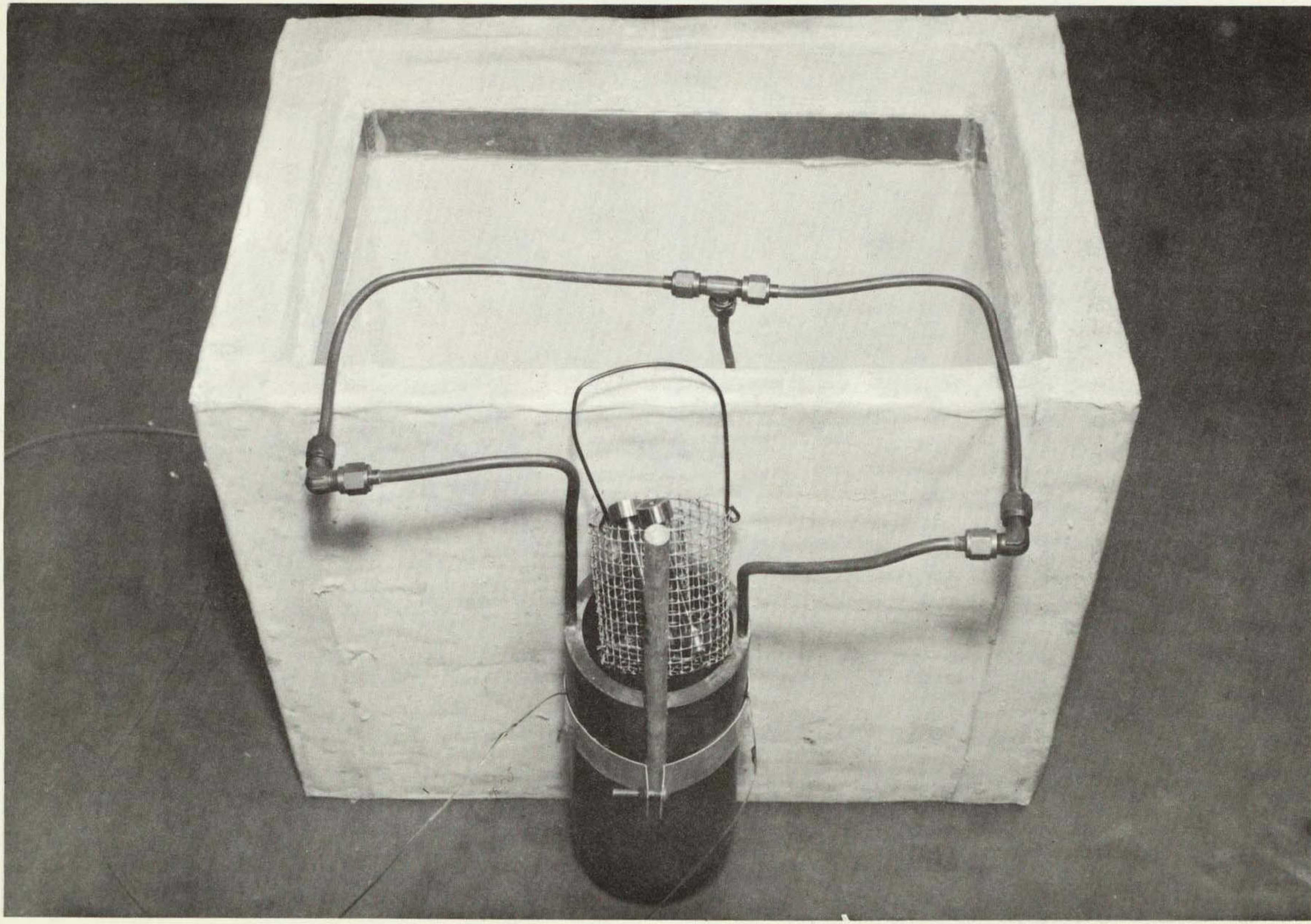
3.3.1 Irradiation of Specimens

The specimens were arranged in the irradiation rack as shown in Figure 3-5. Specimens of a specific type to be tested under similar conditions were grouped so as to receive approximately the



NPC 26,771
31-9493

Figure 3-7 Grips Used in Tensile Tests at 140°R



NPC 26,772
31-9307

Figure 3-8 Fixture Used in Annealing Test Specimens at 440^{O}R same fast-neutron exposure. The specimen layout by serial number is shown in the diagram of Figure 3-9.

During the irradiation, the LN_2 level was maintained above the specimen rack. Upon completion of the irradiation and post-irradiation electrical-resistivity measurements, the tensile specimens were transferred to a storage dewar in the IML.

3.3.2 Axiality Checks

In order to ascertain that the pull rods, the specimen grips, and the test specimens within the grips were all aligned so as to provide axial loading of the test specimens, axiality checks were performed prior to and during the tensile tests.

The axiality checks were made at room temperature using an Instron clip-on extensometer having a 1-in. gage length and a 0.10-in. movement of the strain-gage arm. Extensometer output during calibration and axiality measurements was recorded on a Sanborn recorder. The following procedure was employed in axiality determinations:

1. An unirradiated René 41 specimen was placed in the grips and a load of 150 lb was applied.

2. The extensometer was clipped on and the Sanborn zeroed.

3. Load was then applied by starting the Instron and letting the crosshead travel at the rate of 0.02 in./min until the indicated load on the specimen was 3250 lb. Strain was determined at loads of 1000, 2000, and 3000 lb.

4. Steps 1 through 3 were repeated for extensometer placements at 90-deg intervals around the circumference of the specimen.

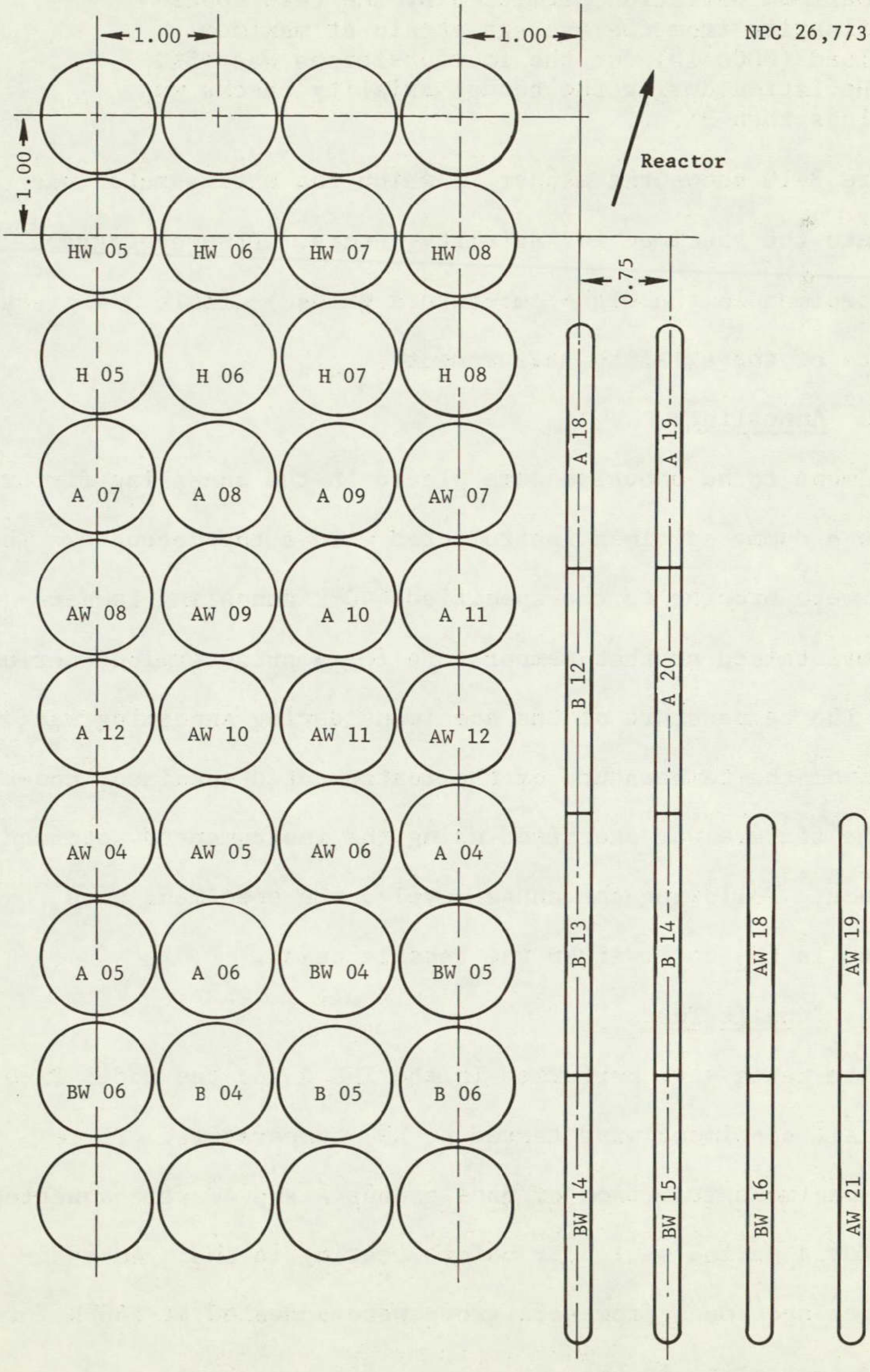


Figure 3-9 Specimen Arrangement for LN_2 Irradiation

5. Maximum deviation permitted by the test specification from the average strain at maximum load (3000 lb) for the four positions was $\pm5\%$. Deviation during the actual axiality checks was less than 3%.

Figure 3-10 shows the manner in which the extensometer was clipped onto the specimen for axiality checks. (The photograph shows a specimen in the high-temperature grips.) Table 3-4 gives the results of the axiality measurements.

3.3.3 Annealing

Specimens to be annealed were placed in the annealing fixture along with a dummy specimen instrumented with a thermocouple. The specimens were brought to the specified $440^{o}R$ annealing temperature and maintained at that temperature for a predetermined period of time. The temperature of the specimens during annealing was inferred from the temperature of the instrumented specimen; control of the fixture was exercised using the instrumented specimen as reference. Following the anneal cycle, the specimens were re-immersed in LN_2 until after the tensile tests.

3.3.4 Tensile Tests

Tensile tests were performed in the IML using the Model TT-D Instron. All specimens were tested at LN_2 temperature. Three aluminum specimens from each of code groups A and AW were annealed at $440^{o}R$ for a period of 1 hour before testing in LN_2. An additional three specimens from each group were annealed at $540^{o}R$ for 1 hour before testing in LN_2.

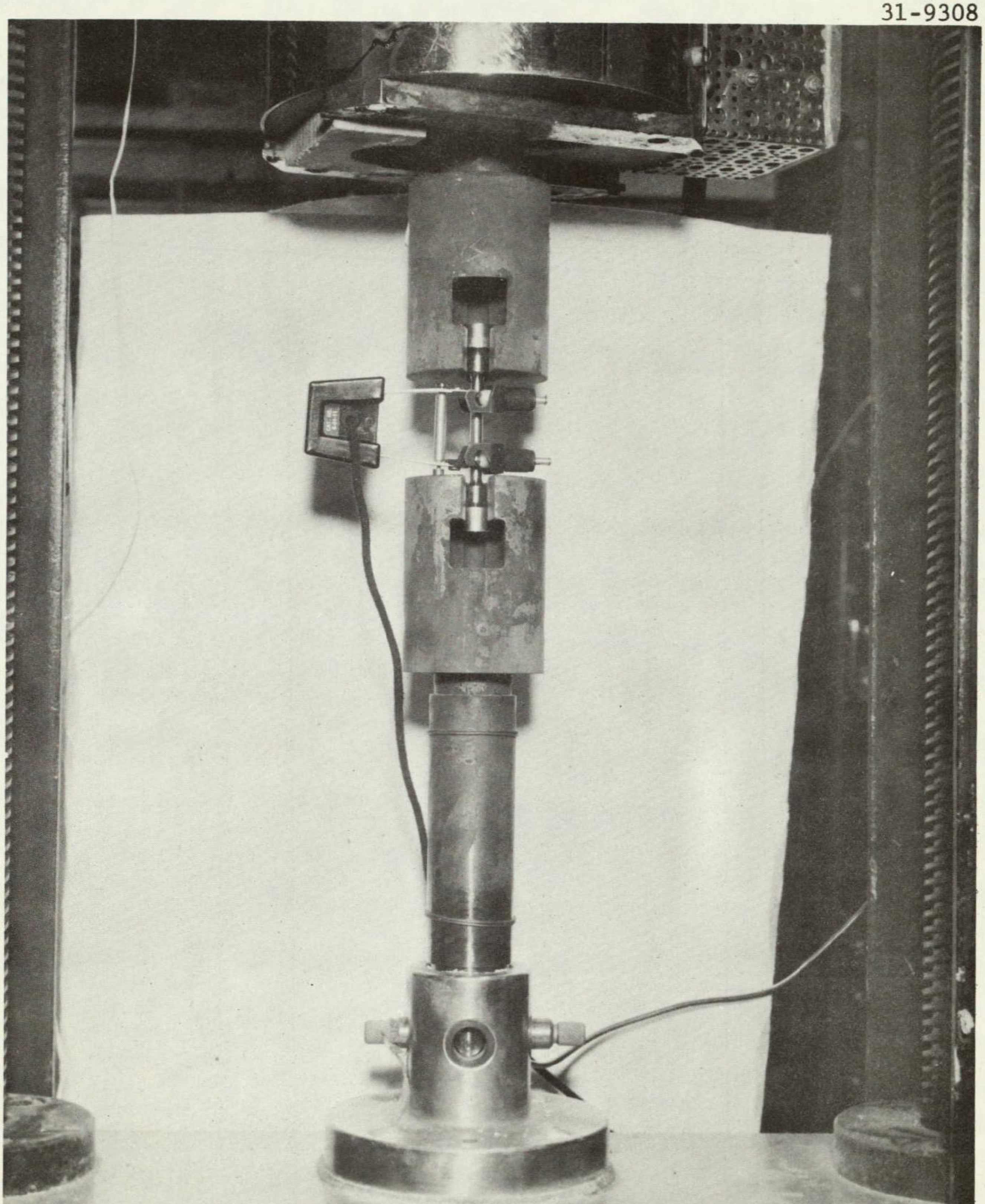


Figure 3-10 Extensometer in Position for Axiality Check

Table 3-4

AXIALITY DATA FOR INSTRON MODEL TT-D PRIOR TO TESTING OF MATERIAL AT 140°R

Specimen: R2 25 (René 41) 8 December 1968

Instron Load (lb)	Sanborn Scale Division Reading[a]						Maximum Deviation (%)
	0°	90°	180°	270°	Avg	Max Dev	
1000[b]	29.5	31.0	34.0	32.0	31.62	2.38	7.53
2000[b]	66.0	68.5	70.0	69.0	68.38	2.38	3.48
3000[b]	102.0	104.0	106.0	104.0	104.0	2.0	1.92
1000[c]	28.5	31.0	31.0	33.0	30.87	2.37	7.68
2000[c]	64.0	67.5	69.0	70.0	67.62	3.62	5.35
3000[c]	100.0	104.0	105.0	106.0	103.75	3.75	3.61

[a]To convert Sanborn Scale Division Reading to inches of extension, multiply given value by 28.6 microinches per division.

[b]Specimen in original position.

[c]Specimen rotated 90° from original position.

With the exception of Hastelloy X, which had four control specimens, three control specimens of each material were tested along with the irradiated specimens. A total of 76 specimens were tested to fracture.

Instron crosshead speed for all specimens was 0.02 in./min, which corresponds to an average strain rate of 0.013 in./in./min in the plastic region and a nominal strain rate of 0.002 in./in./min in the elastic region.*

Specimens were placed in the grips and permitted to "soak" for a period of 15 min before being pulled.

3.3.5 Bench Measurements

Bench-measurement data used for calculating percent elongation and percent reduction of area were obtained with a toolmaker's microscope manufactured by Gaertner Scientific Corporation. The length of each specimen was measured from the inside surfaces of the button heads. The minimum diameter, from which the area reduction was computed, was measured at two locations 90 deg apart. The post-test measurements were made with the broken specimen fitted together. Hardness measurements were made on a standard Rockwell Hardness Tester (Model 3JR).

---

*All average strain rates for the plastic region are the crosshead speed divided by the length of the reduced section of the specimen. The nominal strain rates are based on data obtained in axiality tests.

3.3.6 Macrography

Upon completion of the tensile tests, 10-power photographs were taken of a typical round-unnotched specimen from each test condition.

IV. DISCUSSION AND PRESENTATION OF CRYOGENIC TEST DATA

In order that data of a particular type may be found without undue difficulty, the test results on Aluminum 7039 and Hastelloy X have been compiled separately in Sections 4.2 and 4.3. Each set of data is preceded by an index, or guide, to the tables and figures that follow.

The Discussion of Section 4.1 contains information on the content of the tables and figures and, where necessary, an explanation of terms or methods.

4.1 Discussion

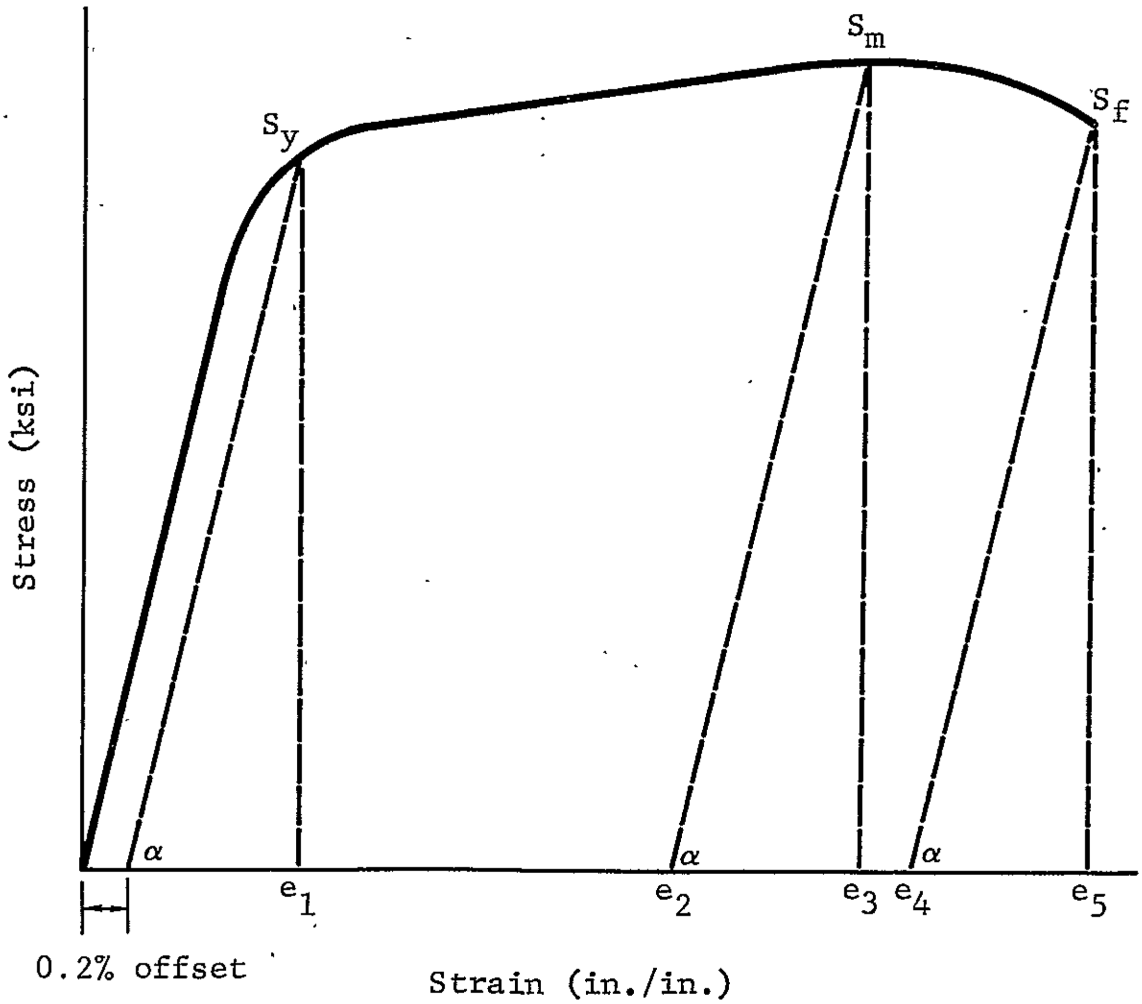
The test results are presented in three forms: data tables, stress-strain curves, and macrographs. The data tables are of two basic types - those containing tensile data on each individual specimen and those in which the effects of test conditions are compared.

4.1.1 Data Tables

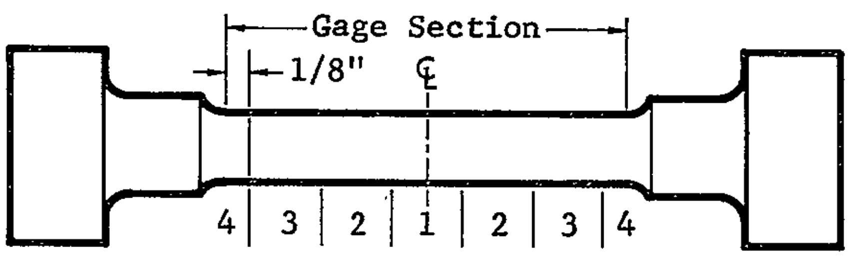
Tensile data for the round-unnotched and the flat-notched specimens of Aluminum 7039 are given in separate tables (only round-unnotched specimens of Hastelloy X were tested). The effects of test conditions on the materials are compared on both an absolute-value basis and a percent-change basis, with the results being shown in the form of bar charts. The method used for these comparisons is discussed in detail in Section 4.1.2.3.

4.1.1.1 Round-Unnotched Specimens

The listing beginning on the opposite page describes the general information and property data that are included in the data tables for the round-unnotched specimens of Aluminum 7039 (Tables 4-1 through 4-4) and Hastelloy X (Tables 4-9 and 4-10). To help define the stress and strain properties included on the list, a classical stress-strain curve is drawn below. The figure contains a graphical representation of all significant stress-strain properties and shows their interrelationships.



1. Designation of the material
2. Specimen configuration and drawing number
3. Specimen number
4. Test condition (control or irradiated)
5. Anneal time and temperature (if any)
6. Yield stress at 0.2% offset (S_y)
7. Strain at 0.2% offset yield point (e_1)
8. Maximum stress (S_m)
9. Plastic strain at maximum stress (e_2)
10. Fracture stress (S_f)
11. Plastic strain at fracture stress (e_4)
12. Percent elongation from both Instron chart and bench measurement
13. Percent reduction in cross-sectional area at fracture point from bench measurements
14. Fracture location specified as 1, 2, 3, or 4 corresponding to the sections indicated in the sketch. Sections 1, 2, and 3 were of an equal length that depended upon the elongation



15. Radiation exposure in terms of gamma dose and fast- and thermal-neutron fluences (see Appendix A for the dosimetry procedures)

16. Plastic and elastic strain at maximum stress (e_3)

17. Total permanent strain (e_4)

18. Plastic and elastic strain at the fracture stress (e_5)

19. Modulus of elasticity based on uncorrected Instron crosshead travel

20. "Resiliency" (computed as the area under the stress-strain curve from (0,0) to an ordinate drawn through the 0.2% offset yield point)

21. "Plasticity" (computed as the area under the stress-strain curve from (0,0) to an ordinate drawn through the maximum stress point)

22. "Energy absorption" (computed as the area under the stress-stain curve from (0,0) to an ordinate drawn through the point of maximum elongation)

23. Rockwell hardness of the material before irradiation and after the tensile test

24. Date on which the tensile test was performed

25. Literature value for modulus of elasticity

In addition to the data for each individual specimen, the data tables give the average, standard deviation, and percent standard deviation for each group of specimens tested under the same condition.

Appendix B (Table B-1) contains supplementary data for each test specimen: the gage-length diameter before and after testing and the gage length (plus shank) before and after testing.

4.1.1.2 Flat-Notched Specimens

The following general information and property data are given in the data tables for the flat-notched specimens of Aluminum 7039:

1. Designation of the material
2. Specimen configuration and drawing number
3. Specimen number
4. Condition (control or irradiated)
5. Ultimate stress
6. Original cross-sectional area at the notch
7. Notch radius (both sides)
8. Rockwell hardness of the material – before and after the test
9. Radiation exposure in terms of gamma dose and fast- and thermal-neutron fluences

In addition to the data for each individual specimen, Tables 4-5 and 4-6 give the average, standard deviation, and percent standard deviation for each group of specimens tested under the same conditions.

The original width and thickness of the specimens are given in Appendix B (Table B-2).

4.1.1.3 Statistical Comparisons

The statistical treatment of the data is based on t-tests for evaluating the significance of observed differences between the average values when changing from one level of the test environment to another. The results of the t-tests are presented graphically as the difference between the averages with a bar indicating the 90% confidence interval. The confidence intervals on an absolute-value basis are

$$\bar{d} \pm t_{\alpha,\zeta} \hat{\sigma} \left(\frac{1}{n_1} + \frac{1}{n_2} \right)^{1/2}$$

where

$\bar{d} = \bar{x}_2 - \bar{x}_1$, where $\bar{x}_1$ and $\bar{x}_2$ are the average values of n_1 and n_2 specimens, respectively

$t_{\alpha,\zeta}$ = the tabular value from the t-table for $\alpha = 0.10$ (90% confidence interval) and ζ degrees of freedom

ζ = (N-P) degrees of freedom associated with the estimate of $\hat{\sigma}$

$\hat{\sigma}$ = the estimated "pooled" standard deviation (see text following)

The confidence intervals on a percent-change basis are

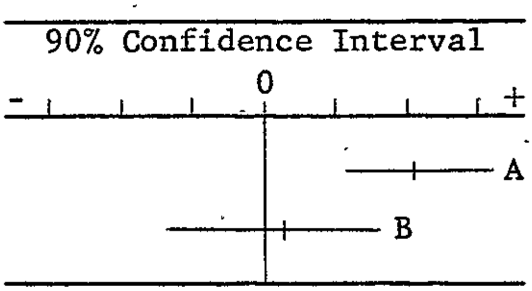
$$\text{P.C.} \pm t_{\alpha,\zeta} \hat{\sigma} \left[\left(\frac{\bar{x}_2}{\bar{x}_1} \right)^2 \left(\frac{1}{n_1 \bar{x}_1^2} + \frac{1}{n_2 \bar{x}_2^2} \right) \right]^{1/2} \times 100$$

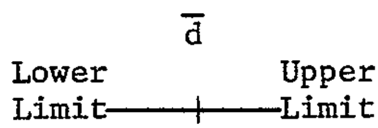
where P.C., the percent change, is

$$\text{P.C.} = 100(\bar{x}_2 - \bar{x}_1)/\bar{x}_1$$

For each measured property the pooled standard deviation, $\hat{\sigma}$, was obtained by combining the individual σ's for each test condition of the material. To illustrate the procedure, consider the round-unnotched specimens of Aluminum 7039-T61 parent. A separate $\hat{\sigma}$ was computed for each of six properties: yield stress, maximum stress, fracture stress, bench-measured elongation, chart-measured elongation, and area reduction. These properties were determined for the N = 11 specimens from the P = 4 test conditions, viz., controls, irradiated, irradiated and annealed at 440°R, and irradiated and annealed at 540°R. The $\hat{\sigma}$ and degrees of freedom are tabulated in Appendix C for each material.

The graphical representation of $\bar{d}$ and the 90% confidence intervals for each comparison derived from the above expressions are illustrated below:





If the interval

$$\bar{d} - t\hat{\sigma}\left[\frac{1}{n_1} + \frac{1}{n_2}\right]^{1/2}, \bar{d} + t\hat{\sigma}\left[\frac{1}{n_1} + \frac{1}{n_2}\right]^{1/2}$$

does not include zero, as in Case A, the interpretation is that there is a significant difference between the average values being compared which cannot be explained by the error variance $\hat{\sigma}^2$. If the interval includes zero, as in Case B, the interpretation is that there is no significant difference between the average values being compared, and that the observed difference can be due to the error variance.

The statistical comparisons are presented in Tables 4-7 and 4-8 for Aluminum 7039 and in Table 4-11 for Hastelloy X. Each comparison is made on both an absolute-value basis and a percent-change basis.

Statistical methods have been used to summarize the data in such a manner as to make them meaningful, and to evaluate, on a probability basis, effects caused by changes from one test condition to another. As in other situations in which mathematics is used as a tool, assumptions are required. The statistical significance test used in the analysis of the data is valid only within the framework of the assumed structure of the variation present in the observations. Random and normally distributed errors and constant variance within classes for a given material and property measurement have been assumed.

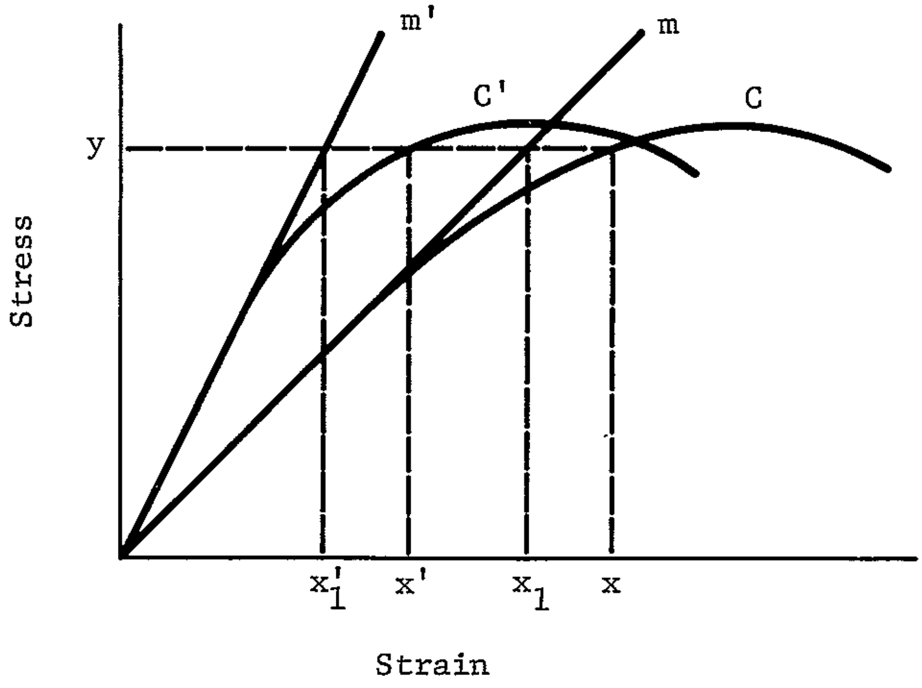
It must be noted that statistical methods determine only the statistical significance of the observed differences in the average values; a difference may be statistically significant and yet be so small as to be of no engineering importance. Also, when a difference is termed non-significant, it does not necessarily mean that there is no difference; it might be that the experiment was not sensitive enough to detect a difference, when in fact such a difference does exist. Also, the standard methods of statistical analysis give no warning of the presence of bias; these techniques assume, in fact, that no bias is present.

4.1.2 Stress-Strain Curves

Stress-strain curves are shown for each round-unnotched tensile specimen. Curves for all specimens (usually three) tested under a given condition have been computer-plotted on one graph. Each stress-strain figure contains the following information:

1. Designation of the material
2. Specimen numbers and plotted symbols
3. Test conditions
4. Stress-strain curves (based on crosshead travel)
5. Strain-measuring device (Instron)
6. Minimum cross-sectional area of specimen
7. Gage length of the specimen (from the design drawing)
8. Radiation exposure (fast- and thermal-neutron fluences and gamma dose)
9. Date the irradiation was completed
10. Date (month and year) of tensile test

Accompanying each set of stress-strain curves is one for a typical specimen for the particular test condition based on a handbook value for the modulus of elasticity. These moduli at 140°R, provided by AGC, are 11.0×10^6 psi for Aluminum 7039 and 32.0×10^6 psi for Hastelloy X. The method used in generating the adjusted stress-strain curves is illustrated by reference to the following sketch of a stress-strain curve, C, plotted directly from the Instron data:



The unadjusted stress-strain curve (C) has a slope (modulus) m. The handbook gives a slope m' which is used to convert Curve C into Curve C'. It is required to transform point x to point x' under the condition that

$$x - x_1 = x' - x_1'$$

Therefore,

$$x' = x - x_1 + x_1' = x - (x_1 - x_1')$$

and from the sketch,

$$x_1 = y/m \quad \text{and} \quad x_1' = y/m'$$

The new abscissa value, x', is then

$$x' = x - (x_1 - x_1') = x - y(1/m - 1/m') = x - ky$$

Therefore, for a given value of stress, y_n, the adjusted strain, x_n', can be computed from the original strain, x_n, and a constant obtained from the original modulus, m, and the desired modulus, m'.

The figures showing the stress-strain curves are presented as pairs - the first, or odd numbered, figure being the curves based on Instron crosshead travel and the second, or even numbered, figure being the stress-strain curve based on the handbook modulus and computed as described above. (Note that the symbol used in the second plot may be different from that used in the first plot. Also, the data points have been largely omitted for the initial linear portions of the curves.) The curves have been plotted with a minimum of scale changes to facilitate comparison of the data. Figures 4-1 through 4-24 are the stress-strain curves for Aluminum 7039, and Figures 4-37 through 4-44 are the curves for Hastelloy X.

4.1.3 Macrographs

A representative specimen (round-unnotched) of each material from each test condition was photographed at ten-power magnification. Two views of the broken end of each selected specimen are shown in Figures 4-25 through 4-36 for the Aluminum 7039 and in Figures 4-45 through 4-48 for Hastelloy X.

Section 4.2

<u>Presentation of</u>
<u>Aluminum 7039 Tensile Data</u>

INDEX TO ALUMINUM 7039 TENSILE DATA

Configuration & Material	Condition	Anneal	Spec. No.	Instron Data		Statistical Comparisons: Absolute Value		Statistical Comparisons: % Change		Stress-Strain Curves: Measured		Stress-Strain Curves: Adjusted		Macrographs	
				Table	Page	Table	Page	Table	Page	Fig.	Page	Fig.	Page	Fig.	Page
Round-Unnotched															
T-61, Parent	Contr	None	A 01 A 02 A 03	4-1	4-16 4-17	4-7	4-26 4-27	4-8	4-28 4-29	4-1	4-30	4-2	4-31	4-25	4-54
	Irrad	None	A 04 A 05 A 06							4-3	4-32	4-4	4-33	4-26	4-55
	Irrad	440°R	A 07 A 08 A 09							4-5	4-34	4-6	4-35	4-27	4-56
	Irrad	540°R	A 10 A 11 A 12							4-7	4-36	4-8	4-37	4-28	4-57
T61, as Welded	Contr	None	AW 01 AW 02 AW 03	4-2	4-18 4-19					4-9	4-38	4-10	4-39	4-29	4-58
	Irrad	None	AW 04 AW 05 AW 06							4-11	4-40	4-12	4-41	4-30	4-59
	Irrad	440°R	AW 07 AW 08 AW 09							4-13	4-42	4-14	4-43	4-31	4-60
	Irrad	540°R	AW 10 AW 11 AW 12							4-15	4-44	4-16	4-45	4-32	4-61
T64, Welded & Treated to T61	Contr	None	BW 01 BW 02 BW 03	4-3	4-20 4-21					4-17	4-46	4-18	4-47	4-33	4-62
	Irrad	None	BW 04 BW 05 BW 06							4-19	4-48	4-20	4-49	4-34	4-63
T64, Parent	Contr	None	B 01 B 02 B 03	4-4	4-22 4-23					4-21	4-50	4-22	4-51	4-35	4-64
	Irrad	None	B 04 B 05 B 06							4-23	4-52	4-24	4-53	4-36	4-65
Flat-Notched															
T61, Parent	Contr	None	A 15 A 16 A 17	4-5	4-24	4-7	4-26	4-8	4-29						
	Irrad	None	A 18 A 19 A 20												
T61, as Welded	Contr	None	AW 15 AW 16 AW 17												
	Irrad	None	AW 18 AW 19 AW 21												
T64, Welded & Treated to T61	Contr	None	BW 11 BW 12 BW 13	4-6	4-25										
	Irrad	None	BW 14 BW 15 BW 16												
T64, Parent	Contr	None	B 09 B 10 B 11 B 16												
	Irrad	None	B 12 B 13 B 14												

Table 4-1

TENSILE TEST DATA FOR INDIVIDUAL ROUND-UNNOTCHED SPECIMENS OF ALUMINUM 7039-T61 PARENT

Specimen configuration: round-unnotched - Dwg. No. AGC 1134298-1. Data to be used for material evaluation only. Do not use for design.

Specimen Number	Condition	Anneal Time & Temp	0.2% Offset Yield Stress (ksi)	Strain @ 0.2% Yield Point (in./in.)	Max Stress (ksi)	Plastic Strain @ Max Stress (in./in.)	Frac Stress (ksi)	Plastic Strain @ Frac Stress (in./in.)	% Elongation		% Area Reduct (Bench)	Frac Loca-tion	Radiation Exposure		
													Gamma Dose [10^{11} ergs/g(C)]	Neutron Fluence (10^{16} n/cm^2)	
									Bench	Chart				Fast E > 1 MeV	Thermal E < 0.48 eV
A 01	Control	None	56.6	0.0185	77.4	0.1165	70.7	0.1732	17.2	17.3	31.0	1			
A 02			57.6	0.0197	77.8	0.1421	71.5	0.1487	14.4	14.9	29.4	2			
A 03			57.1	0.0192	77.8	0.1413	69.8	0.1627	16.3	16.3	34.4	1			
Average			57.1	0.0191	77.7	0.133	70.7	0.161	16.0	16.2	31.6				
Std Dev			0.50	0.0005	0.23	0.015	0.85	0.012	1.43	1.21	2.55				
% Std Dev			0.88	3.14	0.30	10.9	1.20	7.61	8.95	7.46	8.08				
A 04	Irrad	None	Specimen Broke When Being Placed in Instron Grips												
A 05			63.1	0.0204	79.2	0.1079	72.3	0.1400	13.4	14.0	35.6	1	1.1	8.7	2.4
A 06			63.0	0.0211	78.6	0.1066	73.8	0.1393	14.4	13.9	32.6	3	1.2	9.1	2.4
Average			63.1	0.021	78.9	0.107	73.1	0.140	13.9	14.0	34.1				
Std Dev			0.07	0.0005	0.424	0.0009	1.06	0.0005	0.71	0.07	2.12				
% Std Dev			0.11	2.41	0.54	0.86	1.45	0.36	5.09	0.51	6.22				
A 07	Irrad	1 hour at 440° R	59.4	0.0203	78.8	0.1131	71.6	0.1551	15.9	15.5	30.6	1	1.1	8.4	2.0
A 08			60.2	0.0197	79.0	0.1096	71.6	0.1496	15.8	15.0	30.9	2	1.3	10.2	2.0
A 09			60.3	0.019	79.0	0.1100	71.6	0.1466	14.8	14.7	31.5	2	1.5	12.2	2.0
Average			60.0	0.020	78.9	0.111	71.6	0.150	15.5	15.1	31.0				
Std Dev			0.49	0.0004	0.12	0.002	0.0	0.004	0.61	0.40	0.46				
% Std Dev			0.82	1.88	0.15	1.73	0.0	2.87	3.92	2.68	1.48				
A 10	Irrad	1 hour at 540° R	59.1	0.0197	78.3	0.1156	71.5	0.1528	15.8	15.3	31.7	1	1.5	12.1	2.1
A 11			59.2	0.0197	78.4	0.1107	71.5	0.1504	15.0	15.0	30.9	2	1.6	12.7	2.1
A 12			59.0	0.0196	78.2	0.1191	71.5	0.1491	15.9	14.9	31.8	2	1.0	8.3	2.2
Average			59.1	0.020	78.3	0.115	71.5	0.151	15.6	15.1	31.5				
Std Dev			0.10	0.0	0.10	0.004	0.0	0.002	0.49	0.21	0.49				
% Std Dev			0.17	0.0	0.13	3.66	0.0	1.24	3.17	1.38	1.57				

Strain values are based on Instron crosshead travel - not extensometer measurements.
Instron crosshead speed = 0.02 in./min = average strain rate in plastic region of 0.013 in./in./min (based on 1.5-in. gage length)
Irradiation Completion Date: 3 November 1967
Irradiation and tensile-test temperature: 140°R

Table 4-1 (Cont'd)

Specimen Number	Condition	Plastic & Elastic Strain @ Max Stress (in./in.)	Total Permanent Strain (in./in.)	Plastic & Elastic Strain @ Frac Stress (in./in.)	Modulus of Elasticity[a] (10^6 psi)	Resiliency (in.-lb/in.^{3})	Plasticity (in.-lb/in.^{3})	Energy Absorption (in.-lb/in.^{3})	Hardness, Rockwell E Scale		Test Date (Dec 67)
									As Received	After Testing	
A 01	Control	0.1391	0.1732	0.1939	3.4	578	9,182	13,352	98.0	96.8	13
A 02		0.1421	0.1488	0.1705	3.3	622	9,441	11,602	98.2	96.6	
A 03		0.1413	0.1627	0.1833	3.4	603	9,385	12,577	97.5	96.4	
Average		0.141	0.162	0.183	3.4	601	9,336	12,510	97.9	96.6	
Std Dev		0.002	0.012	0.012	0.058	22.1	136.3	877	0.36	0.20	
% Std Dev		1.10	7.61	6.42	1.72	3.67	1.46	7.01	0.37	0.21	
A 04	Irrad	Specimen Broke When Being Placed in Instron Grips							98.2	-	14
A 05		0.1311	0.1400	0.1612	3.4	695	8,913	11,244	98.2	96.8	
A 06		0.1304	0.1393	0.1616	3.3	723	8,776	11,195	97.5	95.9	
Average		0.1308	0.1397	0.161	3.35	709	8,845	11,219	98.0	96.4	
Std Dev		0.0005	0.0005	0.0003	0.07	19.8	96.9	34.7	0.40	0.64	
% Std Dev		0.38	0.36	0.18	2.11	2.79	1.10	0.31	0.41	0.66	
A 07	Irrad	0.1375	0.1551	0.1773	3.2	650	9,223	12,301	97.9	95.7	14
A 08		0.1327	0.1496	0.1705	3.4	650	8,899	11,827	98.0	96.1	
A 09		0.1333	0.1466	0.1677	3.4	639	8,968	11,623	98.1	95.3	
Average		0.1345	0.1504	0.172	3.33	646	9,030	11,917	98.0	95.7	
Std Dev		0.003	0.004	0.005	0.12	6.35	170.7	347.8	0.10	0.40	
% Std Dev		1.94	2.87	2.87	3.46	0.98	1.89	2.92	0.10	0.42	
A 10	Irrad	0.1387	0.1528	0.1739	3.4	641	9,274	11,947	99.3	98.6	14
A 11		0.1340	0.1504	0.1717	3.4	640	8,924	11,821	99.5	99.3	
A 12		0.1423	0.1491	0.1703	3.4	638	9,562	11,700	99.3	99.1	
Average		0.1383	0.1508	0.172	3.4	640	9,253	11,831	99.4	99.0	
Std Dev		0.004	0.002	0.002	0.0	1.53	319.5	137.3	0.12	0.36	
% Std Dev		3.01	1.24	1.06	0.0	0.24	3.45	1.16	0.12	0.36	

[a] Moduli reported are based on uncorrected Instron measurements. Literature value for modulus of elasticity for control specimens of this material at 140°R is 11.0×10^6 psi.

Table 4-2

TENSILE TEST DATA FOR INDIVIDUAL ROUND-UNNOTCHED SPECIMENS OF ALUMINUM 7039-T61 AS-WELDED

Specimen configuration: round-unnotched - Dwg. No. AGC 1134298-1. Data to be used for material evaluation only. Do not use for design.

Specimen Number	Condition	Anneal Time & Temp	0.2% Offset Yield Stress (ksi)	Strain @ 0.2% Yield Point (in./in.)	Max Stress (ksi)	Plastic Strain @ Max Stress (in./in.)	Frac Stress (ksi)	Plastic Strain @ Frac Stress (in./in.)	% Elongation		% Area Reduct (Bench)	Frac Loca-tion	Radiation Exposure		
									Bench	Chart			Gamma Dose [10^{11} ergs/g(C)]	Neutron Fluence (10^{16} n/cm^2) Fast $E > 1$ MeV	Thermal $E < 0.48$ eV
AW 01	Control	None	32.4	0.0141	60.0	0.1061	60.0	0.1061	11.5	10.6	29.3	1			
AW 02			30.9	0.0129	60.5	0.1353	60.2	0.1353	14.5	13.5	28.3	2			
AW 03			31.8	0.0132	60.1	0.1217	59.4	0.1250	12.9	12.5	31.1	1			
Average			31.7	0.0134	60.2	0.121	59.9	0.122	13.0	12.2	29.6				
Std Dev			0.76	0.0006	0.265	0.015	0.42	0.015	1.50	1.47	1.42				
% Std Dev			2.38	4.66	0.44	12.1	0.70	12.1	11.6	12.1	4.80				
AW 04	Irrad	None	40.2	0.0145	58.4	0.1118	57.9	0.1147	12.3	11.5	32.2	2	1.1	8.5	2.3
AW 05			41.1	0.0149	56.8	0.1084	56.5	0.1150	12.1	11.5	35.1	2	1.2	9.5	2.3
AW 06			42.7	0.0155	58.7	0.1044	58.4	0.1078	10.6	10.8	29.9	2	1.4	11.5	2.3
Average			41.3	0.015	58.0	0.108	57.6	0.113	11.7	11.3	32.4				
Std Dev			1.27	0.0005	1.02	0.004	0.99	0.004	0.93	0.40	2.61				
% Std Dev			3.06	3.34	1.76	3.42	1.71	3.62	7.96	3.59	8.04				
AW 07	Irrad	1 hour at 440° R	38.0	0.0147	60.7	0.1261	60.1	0.1275	12.0	12.8	26.7	1	1.7	13.5	2.0
AW 08			35.5	0.0149	58.2	0.1067	55.2	0.1091	11.5	10.9	27.2	2	1.1	8.9	2.1
AW 09			34.7	0.0135	57.1	0.1155	56.8	0.1227	11.8	12.3	32.4	1	1.3	10.2	2.1
Average			36.1	0.0144	58.7	0.1161	57.4	0.120	11.8	12.0	28.8				
Std Dev			1.72	0.0008	1.85	0.0010	2.50	0.010	0.25	0.99	3.16				
% Std Dev			4.77	5.26	3.15	8.37	4.36	7.97	2.14	8.21	11.0				
AW 10	Irrad	1 hour at 540°R	30.3	0.0129	56.1	0.1056	54.5	0.1095	11.3	11.0	32.1	1	1.2	9.8	2.2
AW 11			31.7	0.0135	58.5	0.1358	57.3	0.1385	13.9	13.9	32.4	1	1.5	11.9	2.2
AW 12			31.6	0.0132	56.7	0.1338	56.3	0.1159	11.8	11.6	33.4	2	1.5	12.1	2.2
Average			31.2	0.0132	57.1	0.125	56.0	0.121	12.3	12.2	32.6				
Std Dev			0.78	0.0003	1.25	0.017	1.42	0.015	1.38	1.53	0.68				
% Std Dev			2.50	2.27	2.19	13.5	2.53	12.6	11.2	12.6	2.08				

Strain values are based on Instron crosshead travel - not extensometer measurements.
Instron crosshead speed = 0.02 in./min = average strain rate in plastic region of 0.013 in./in./min (based on 1.5-in. gage length)
Irradiation Completion Date: 3 November 1967
Irradiation and tensile test temperature: 140°R

Table 4-2 (Cont'd)

Specimen Number	Condition	Plastic & Elastic Strain @ Max Stress (in./in.)	Total Permanent Strain (in./in.)	Plastic & Elastic Strain @ Frac Stress (in./in.)	Modulus of Elasticity[a] (10^6 psi)	Resiliency (in.-lb/in.^{3})	Plasticity (in.-lb/in.^{3})	Energy Absorption (in.-lb/in.^{3})	Hardness, Rockwell E Scale: As Received	Hardness, Rockwell E Scale: After Testing	Test Date (Dec 67)
AW 01	Control	0.1292	0.1061	0.1292	2.6	250	6,047	6,047	97.8	96.4	15
AW 02		0.1571	0.1353	0.1571	2.8	223	7,629	7,629	97.4	96.7	
AW 03		0.1427	0.1250	0.1457	2.9	238	6,847	7,031	98.0	96.7	
Average		0.1430	0.1221	0.144	2.8	237	6,841	6,902	97.7	96.6	
Std Dev		0.014	0.015	0.014	0.15	13.5	791	798.8	0.31	0.17	
% Std Dev		9.76	12.1	9.74	5.52	5.71	11.5	11.6	0.31	0.18	
AW 04	Irrad	0.1301	0.1147	0.1329	3.2	326	6,378	6,541	97.5	95.6	15
AW 05		0.1267	0.1150	0.1331	3.1	336	6,129	6,493	97.3	95.9	
AW 06		0.1232	0.1078	0.1265	3.1	359	6,113	6,309	96.9	96.2	
Average		0.1267	0.1125	0.131	3.1	340	6,207	6,448	97.2	95.9	
Std Dev		0.003	0.004	0.004	0.006	16.9	148.6	122.5	0.31	0.30	
% Std Dev		2.72	3.62	2.87	1.84	4.97	2.39	1.90	0.31	0.31	
AW 07	Irrad	0.1464	0.1275	0.1475	3.0	311	7,349	7,422	97.6	96.1	15
AW 08		0.1279	0.1091	0.1292	2.8	298	5,989	6,064	96.7	95.5	
AW 09		0.1343	0.1227	0.1413	3.0	263	6,298	6,701	97.3	96.8	
Average		0.1362	0.1197	0.139	2.9	290	6,545	6,729	97.2	96.1	
Std Dev		0.009	0.009	0.009	0.116	24.8	712.9	679.4	0.46	0.65	
% Std Dev		6.90	7.97	6.68	3.94	8.54	10.89	10.10	0.47	0.68	
AW 10	Irrad	0.1258	0.1095	0.1291	2.8	223	5,530	5,716	97.2	95.4	15
AW 11		0.1573	0.1384	0.1596	2.7	237	7,490	7,622	97.5	95.9	
AW 12		0.1336	0.1160	0.1356	2.9	239	6,075	6,188	97.0	94.3	
Average		0.1389	0.121	0.141	2.8	233	6,365	6,509	97.2	95.2	
Std Dev		0.016	0.015	0.016	0.10	8.72	1,011	993	0.25	0.82	
% Std Dev		11.8	12.6	11.4	3.57	3.74	15.9	15.3	0.26	0.86	

[a]Moduli reported are based on uncorrected Instron measurements. Literature value for modulus of elasticity for control specimens of this material at 140°R is 11.0 x 10^6 psi.

Table 4-3

TENSILE TEST DATA FOR INDIVIDUAL ROUND-UNNOTCHED SPECIMENS OF ALUMINUM 7039-T64 WELDED AND TREATED TO T61

Specimen configuration: round-unnotched - Dwg. No. AGC 1134298-1. Data to be used for material evaluation only. Do not use for design

Specimen Number	Condition	0.2% Offset Yield Stress (ksi)	Strain @ 0.2% Yield Point (in./in.)	Max Stress (ksi)	Plastic Strain @ Max Stress (in./in.)	Frac Stress (ksi)	Plastic Strain @ Frac Stress (in./in.)	% Elongation		% Area Reduct (Bench)	Frac Location	Radiation Exposure		
								Bench	Chart			Gamma Dose [10^{11} ergs/g(C)]	Neutron Fluence (10^{16} n/cm^2) Fast $E>1$ MeV	Thermal $E<0.48$ eV
BW 01	Control	28.1	0.0113	56.0	0.0717	51.3	0.0813	8.1	8.1	35.2	2			
BW 02		32.0	0.0133	57.9	0.0677	57.3	0.0726	7.5	7.3	31.2	1			
BW 03		30.9	0.0129	58.2	0.0811	57.3	0.0993	10.6	9.9	34.3	1			
Average		30.3	0.0130	57.4	0.0740	55.3	0.084	8.7	8.4	33.6				
Std Dev		2.01	0.001	1.19	0.007	3.46	0.014	1.64	1.33	2.01				
% Std Dev		6.63	8.47	2.08	9.36	6.26	16.13	18.83	15.8	6.25				
BW 04	Irrad	44.0	0.0159	60.0	0.0682	58.3	0.0692	7.3	6.9	30.6	1	1.3	10.7	2.4
BW 05		44.5	0.0169	59.7	0.0658	58.8	0.0671	6.6	6.7	26.3	1	1.4	11.3	2.4
BW 06		41.3	0.0148	59.0	0.0654	58.2	0.0754	7.6	7.5	33.8	1	1.1	9.0	2.5
Average		43.3	0.0160	59.6	0.0670	58.4	0.0710	7.2	7.0	30.2				
Std Dev		1.72	0.001	0.51	0.002	0.32	0.004	0.51	0.42	3.76				
% Std Dev		3.98	6.61	0.86	2.28	0.55	6.12	7.16	5.92	12.4				

Strain values are based on Instron crosshead travel - not extensometer measurements.
Instron crosshead speed = 0.02 in./min = average strain rate in plastic region of 0.013 in./in./min (based on 1.5-in. gage length)
Irradiation Completion Date: 3 November 1967
Irradiation and tensile test temp: 140°R

Table 4-3 (Cont'd)

Specimen Number	Condition	Plastic & Elastic Strain @ Max Stress (in./in.)	Total Permanent Strain (in./in.)	Plastic & Elastic Strain @ Frac Stress (in./in.)	Modulus of Elasticity[a] (10^6 psi)	Resiliency (in.-lb/in.^{3})	Plasticity (in.-lb/in.^{3})	Energy Absorption (in.-lb/in.^{3})	Hardness, Rockwell B Scale: As Received	Hardness, Rockwell B Scale: After Testing	Test Date (Dec 67)
BW 01	Control	0.0900	0.0813	0.0987	3.0	180	3,945	4,423	73.9	70.2	18
BW 02		0.0880	0.0762	0.0927	2.9	239	4,008	4,277	74.2	71.1	
BW 03		0.1017	0.0993	0.1196	2.8	222	5,715	4,678	75.1	71.6	
Average		0.0932	0.086	0.104	2.9	214	4,556	4,459	74.4	71.0	
Std Dev		0.007	0.012	0.014	0.10	30.4	1,004	203	0.62	0.71	
% Std Dev		7.94	14.2	13.6	3.45	14.2	22.0	4.55	0.84	1.00	
BW 04	Irrad	0.0873	0.0692	0.0877	3.1	387	4,363	4,387	73.8	71.2	18
BW 05		0.0803	0.0671	0.0865	3.0	418	3,940	4,308	73.4	69.7	
BW 06		0.0835	0.0754	0.0932	3.3	344	4,037	4,608	73.3	71.3	
Average		0.084	0.071	0.089	3.1	383	4,113	4,434	73.5	70.7	
Std Dev		0.004	0.004	0.004	0.15	37.1	221.6	155.5	0.26	0.90	
% Std Dev		4.19	6.12	4.001	4.88	9.70	5.39	3.51	0.36	1.27	

[a]Moduli reported are based on uncorrected Instron measurements. Literature value for modulus of elasticity for control specimens of this material at 140°R is 11.0 x 10^6 psi.

Table 4-4

TENSILE TEST DATA FOR INDIVIDUAL ROUND-UNNOTCHED SPECIMENS OF ALUMINUM 7039-T64 PARENT

Specimen configuration: round-unnotched - Dwg. No. AGC 1134298-1. Data to be used for material evaluation only. Do not use for design.

Specimen Number	Condition	0.2% Offset Yield Stress (ksi)	Strain @ 0.2% Yield Point (in./in.)	Max Stress (ksi)	Plastic Strain @ Max Stress (in./in.)	Frac Stress (ksi)	Plastic Strain @ Frac Stress (in./in.)	% Elongation		% Area Reduct (Bench)	Frac Location	Radiation Exposure		
								Bench	Chart			Gamma Dose [10^{11} ergs/g (C)]	Neutron Fluence (10^{16} n/cm^2)	
													Fast E > 1 MeV	Thermal E < 0.48 eV
B 01	Control	67.7	0.0215	84.7	0.1341	80.1	0.1350	13.3	13.5	27.9	1			
B 02		67.8	0.0215	85.0	0.1357	81.7	0.1481	15.1	14.8	31.1	2			
B 03		67.8	0.0220	84.7	0.1144	80.8	0.1384	13.3	13.8	27.1	1			
Average		67.8	0.0217	84.8	0.128	80.9	0.141	13.9	14.0	28.7				
Std Dev		0.058	0.0003	0.17	0.012	0.80	0.007	1.04	0.68	2.12				
% Std Dev		0.09	1.31	0.20	9.26	0.99	4.84	7.48	4.85	7.38				
B 04	Irrad	72.9	0.0232	85.6	0.1005	81.5	0.1317	12.9	13.2	23.9	1	1.1	8.8	2.5
B 05		73.2	0.0233	85.4	0.1059	80.8	0.1315	12.5	13.2	23.1	1	1.2	9.7	2.5
B 06		74.1	0.0236	86.0	0.1035	81.1	0.1352	13.1	13.5	21.9	1	1.4	11.1	2.5
Average		73.4	0.023	85.7	0.103	81.1	0.133	12.8	13.3	23.0				
Std Dev		0.62	0.0002	0.31	0.003	0.35	0.002	0.30	0.17	1.01				
% Std Dev		0.85	0.86	0.36	2.62	0.43	1.57	2.38	1.31	4.38				

Strain values are based on Instron crosshead travel - not extensometer measurements.
Instron crosshead speed = 0.02 in./min = average strain rate in plastic region of 0.013 in./in./min (based on 1.5-in. gage length)
Irradiation Completion Date: 3 November 1967
Irradiation and tensile test temperature: 140°R

Table 4-4 (Cont'd)

Specimen Number	Condition	Plastic & Elastic Strain @ Max Stress (in./in.)	Total Permanent Strain (in./in.)	Plastic & Elastic Strain @ Frac Stress (in./in.)	Modulus of Elasticity[a] (10^6 psi)	Resiliency (in.-lb/in.^{3})	Plasticity (in.-lb/in.^{3})	Energy Absorption (in.-lb/in.^{3})	Hardness, Rockwell B Scale: As Received	Hardness, Rockwell B Scale: After Testing	Test Date (Dec 67)
B 01	Control	0.1341	0.1350	0.1580	3.4	788	9,765	11,754	77.0	75.2	15
B 02		0.1357	0.1481	0.1719	3.4	786	9,904	12,950	76.8	73.8	
B 03		0.1384	0.1384	0.1613	3.5	776	10,131	12,046	75.1	71.1	
Average		0.136	0.140	0.164	3.4	783	9,933	12,250	76.3	73.4	
Std Dev		0.002	0.007	0.007	0.06	6.43	184.8	623.6	1.04	2.08	
% Std Dev		1.60	4.84	4.44	1.68	0.87	1.86	5.09	1.37	2.84	
B 04	Irrad	0.1253	0.1317	0.1553	3.5	910	9,229	11,764	77.4	72.8	15
B 05		0.1307	0.1315	0.1549	3.4	916	9,667	11,704	77.1	74.6	
B 06		0.1287	0.1352	0.1589	3.4	942	9,575	12,138	77.2	72.7	
Average		0.128	0.133	0.156	3.4	922	9,490	11,868	77.2	73.4	
Std Dev		0.003	0.002	0.002	0.06	17.0	231.0	235.2	0.15	1.07	
% Std Dev		2.13	1.57	1.41	1.68	1.84	2.43	1.98	0.20	1.46	

[a]Moduli reported are based on uncorrected Instron measurements. Literature value for modulus of elasticity for control specimens of this material at 140°R is 11.0 x 10^6 psi.

Table 4-5

TENSILE TEST DATA FOR INDIVIDUAL FLAT-NOTCHED SPECIMENS OF ALUMINUM 7039-T61 PARENT AND ALUMINUM 7039-T61 AS-WELDED

Specimen Configuration: flat-notched - Dwg. No. AGC 1134350-3 Data to be used for material evaluation only. Do not use for design.

Material	Specimen Number	Condition	Ultimate Stress (ksi)	Original X-Sectional Area @ Notch (in.^{2})	Notch Radius (in.)		Hardness, Rockwell E Scale		Radiation Exposure		
									Gamma Dose [10^{11} ergs/g(C)]	Neutron Fluence (10^{17} n/cm^2)	
					Side 1	Side 2	As Received	After Testing		Fast E >1 MeV	Thermal E < 0.48 eV
Aluminum 7039-T61, Parent	A 15	Control	57.8	0.1303	0.0015	0.0009	99.0	99.2			
	A 16		63.8	0.1312	0.0010	0.0010	98.9	99.2			
	A 17		58.3	0.1325	0.0010	0.0008	99.3	99.0			
	Average		60.0				99.1	99.1			
	Std Dev		3.33				0.21	0.12			
	% Std Dev		5.55				0.21	0.12			
	A 18	Irrad	69.8	0.1328	0.0010	0.0010	98.3	98.6	2.2	1.8	0.25
	A 19		64.9	0.1303	0.0015	0.0010	98.5	99.3	3.1	2.5	0.25
	A 20		62.3	0.1327	0.0015	0.0010	99.3	99.1	2.7	2.2	0.23
	Average		65.7				98.7	99.0			
	Std Dev		3.81				0.53	0.36			
	% Std Dev		5.80				0.54	0.36			
Aluminum 7039-T61, as Welded	AW 15	Control	41.4	0.1276	0.0010	0.0010	97.6	99.0			
	AW 16		46.3	0.1252	0.0010	0.0008	98.5	99:5			
	AW 17		46.4	0.1273	0.0015	0.0014	99.4	99.1			
	Average		44.7				98.5	99.2			
	Std Dev		2.86				0.90	0.26			
	% Std Dev		6.39				0.91	0.27			
	AW 18	Irrad	52.0	0.1257	0.0013	0.0012	99.3	97.7	2.4	1.9	0.22
	AW 19		51.9	0.1310	0.0010	0.0010	99.2	98.3	2.6	2.1	0.22
	AW 21		51.1	0.1272	0.0010	0.0014	98.4	98.0	2.4	1.9	0.20
	Average		51.7				99.0	98.0			
	Std Dev		0.49				0.49	0.30			
	% Std Dev		0.95				0.50	0.31			

Instron crosshead speed = 0.02 in./min
Irradiation completion date: 3 November 67; test date: 20 December 67
Irradiation and tensile test temp: 140°R

Table 4-6

TENSILE TEST DATA FOR INDIVIDUAL FLAT-NOTCHED SPECIMENS OF ALUMINUM 7039-T64 WELDED AND TREATED TO T61 AND ALUMINUM 7039-T64 PARENT

Specimen Configuration: flat-notched - Dwg. No. AGC 1134350-3 Data to be used for material evaluation only. Do not use for design.

Material	Specimen Number	Condition	Ultimate Stress (ksi)	Original X-Sectional Area @ Notch (in.^{2})	Notch Radius (in.)		Hardness, Rockwell B Scale		Radiation Exposure		
									Gamma Dose [10^{11} ergs/g(C)]	Neutron Fluence (10^{17} n/cm^2)	
					Side 1	Side 2	As Received	After Testing		Fast E > 1 MeV	Thermal E < 0.48 eV
Aluminum 7039-T64, Welded & Treated to T61	BW 11	Control	42.6	0.1315	0.0015	0.0011	74.6	72.8			
	BW 12		40.9	0.1320	0.0015	0.0010	74.7	71.7			
	BW 13		45.6	0.1317	0.0015	0.0009	75.7	72.2			
	Average		43.0				75.0	72.2			
	Std Dev		2.38				0.61	0.55			
	% Std Dev		5.53				0.81	0.76			
	BW 14	Irrad	52.2	0.1328	0.0010	0.0008	74.3	72.1	1.7	1.4	0.20
	BW 15		50.1	0.1333	0.0010	0.0010	72.9	72.8	1.9	1.5	0.20
	BW 16		54.7	0.1326	0.0007	0.0010	74.3	72.6	2.1	1.7	0.20
	Average		52.3				73.8	72.5			
	Std Dev		2.30				0.81	0.36			
	% Std Dev		4.40				1.09	0.50			
Aluminum 7039-T64, Parent	B 09	Control	65.9	0.1326	0.0012	0.0015	76.9	74.5			
	B 10		46.3[a]	0.1330	0.0011	0.0010	76.7	74.3			
	B 11		65.1	0.1326	0.0008	0.0010	76.9	74.1			
	B 16		64.9	0.1319	0.0010	0.0010	77.1	76.1			
	Average		65.3				76.9	74.8			
	Std Dev		0.53				0.16	0.91			
	% Std Dev		0.81				0.21	1.22			
	B 12	Irrad	73.2	0.1338	0.0008	0.0010	75.6	74.1	2.1	1.7	0.23
	B 13		67.3	0.1329	0.0008	0.0010	76.6	75.2	1.9	1.5	0.22
	B 14		71.3	0.1324	0.0010	0.0010	75.7	74.8	2.1	1.7	0.22
	Average		70.6				76.0	74.7			
	Std Dev		3.01				0.55	0.56			
	% Std Dev		4.27				0.72	0.75			

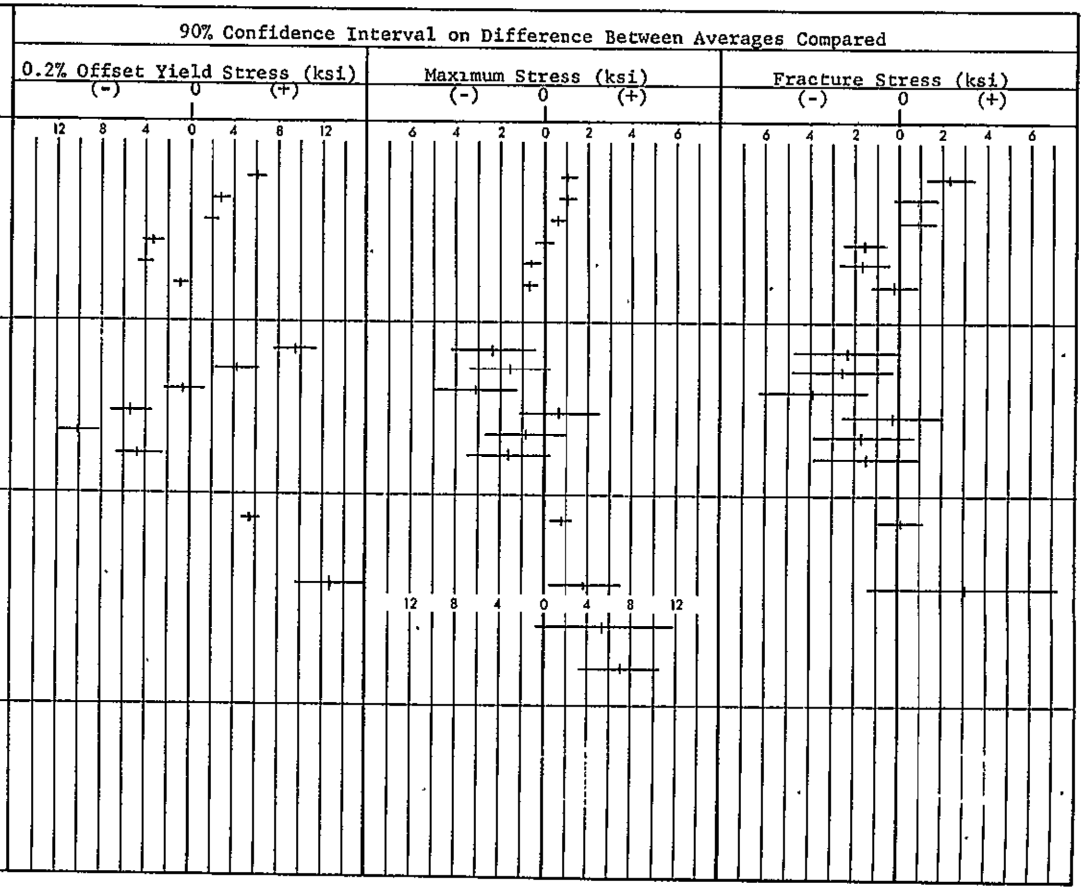
Instron crosshead speed = 0.02 in./min
Irradiation completion date: 3 November 67; test date: 20 or 21 December 67
Irradiation and tensile test temp: 140°R

[a]Not included in average

Table 4-7

EFFECT OF TEST CONDITIONS ON THE PROPERTIES OF ALUMINUM 7039 -
COMPARISON ON AN ABSOLUTE-VALUE BASIS

Material	Specimen Data Compared[a]
Al 7039-T61, parent	Control vs irradiated Control vs irrad & anneal @ 440°R Control vs irrad & anneal @ 540°R Irrad vs irrad & anneal @ 440°R Irrad vs irrad & anneal @ 540°R Irrad & anneal @ 440°R vs irrad & anneal @ 540°R
Al 7039-T61, as welded	Control vs irradiated Control vs irrad & anneal @ 440°R Control vs irrad & anneal @ 540°R Irrad vs irrad & anneal @ 440°R Irrad vs irrad & anneal @ 540°R Irrad & anneal @ 440°R vs irrad & anneal @ 540°R
Al 7039-T64, parent	Control vs irradiated
Al 7039-T64, welded & treated to T61	Control vs irradiated
Al 7039-T61, parent[b]	Control vs irradiated
Al 7039-T61, as welded[b]	Control vs irradiated

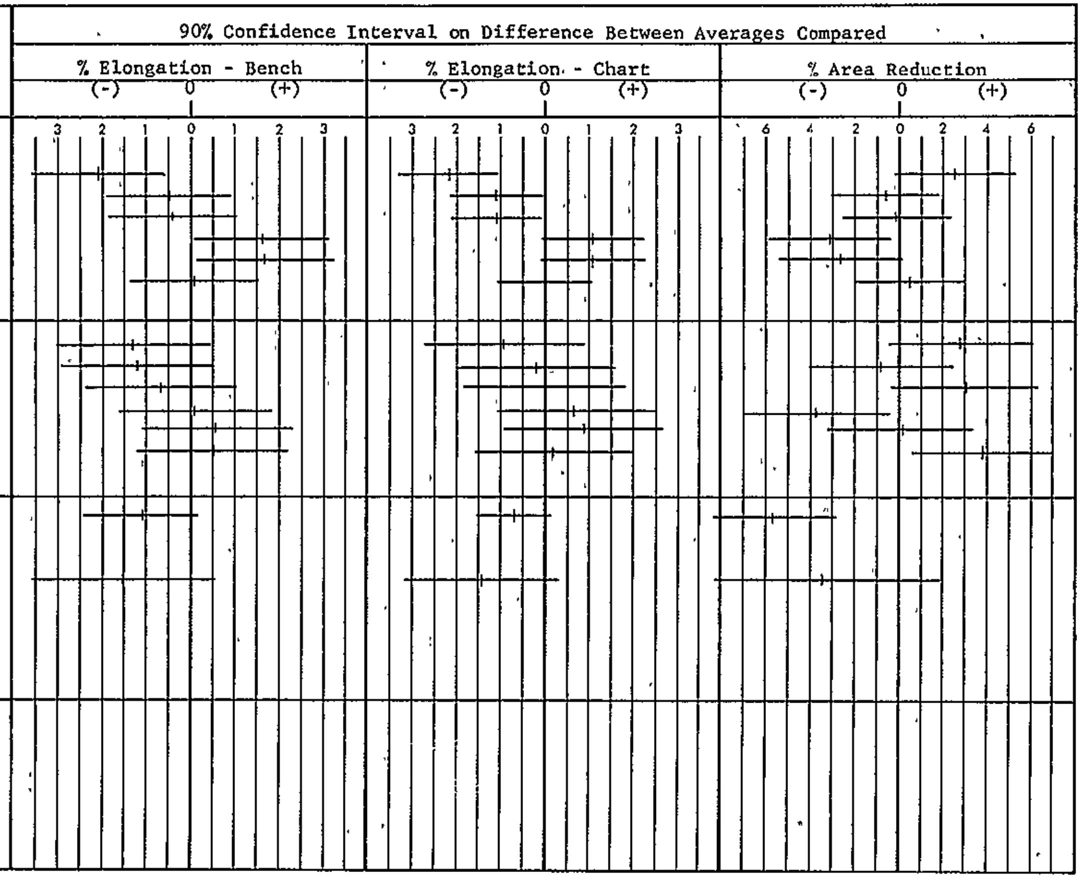


[a] Comparison is always second condition compared to the first condition.

[b] Flat tensile specimens; all others round specimens.

Table 4-7 (Cont'd)

Material	Specimen Data Compared[a]
Al 7039-T61, parent	Control vs irradiated Control vs irrad & anneal @ 440°R Control vs irrad & anneal @ 540°R Irrad vs irrad & anneal @ 440°R Irrad vs irrad & anneal @ 540°R Irrad & anneal @ 440°R vs irrad & anneal @ 540°R
Al 7039-T61, as welded	Control vs irradiated Control vs irrad & anneal @ 440°R Control vs irrad & anneal @ 540°R Irrad vs irrad & anneal @ 440°R Irrad vs irrad & anneal @ 540°R Irrad & anneal @ 440°R vs irrad & anneal @ 540°R
Al 7039-T64, parent	Control vs irradiated
Al 7039-T64, welded & treated to T61	Control vs irradiated

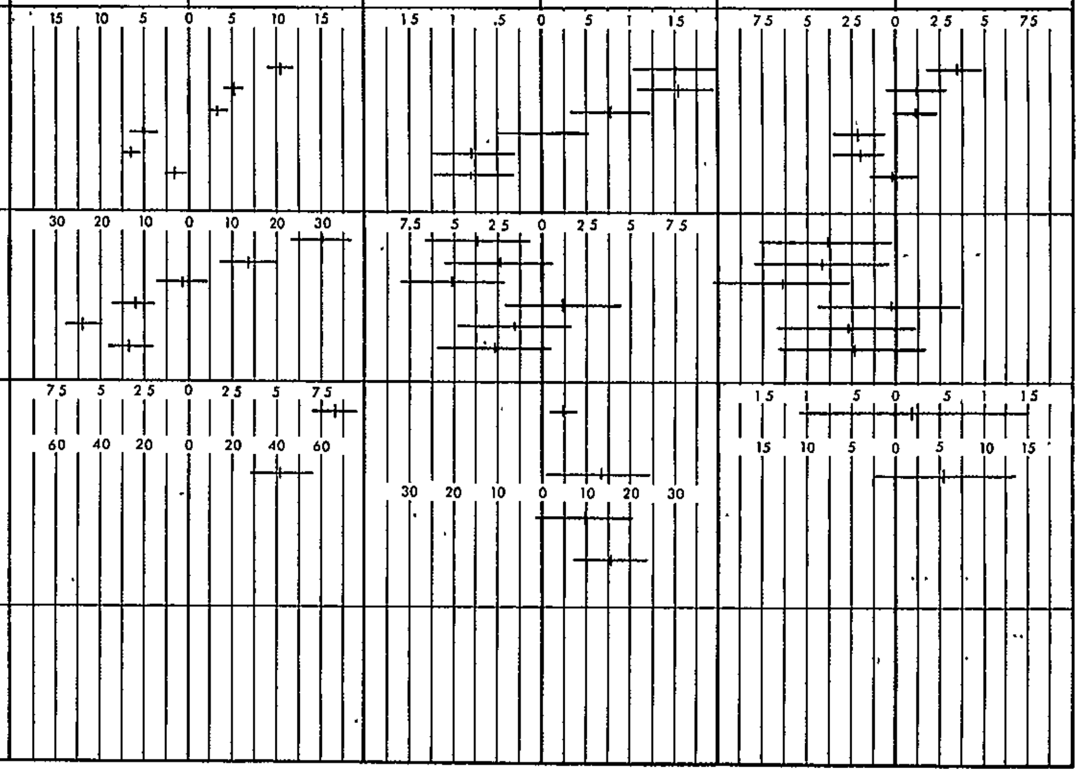


[a] Comparison is always second condition compared to the first condition.

Table 4-8

EFFECT OF TEST CONDITIONS ON THE PROPERTIES OF ALUMINUM 7039 - COMPARISON ON A PERCENT-CHANGE BASIS

Material	Specimen Data Compared[a]	90% Confidence Interval on Difference Between Averages Compared: 0.2% Offset Yield Stress (-) 0 (+)	Maximum Stress (-) 0 (+)	Fracture Stress (-) 0 (+)
Al 7039-T61, parent	Control vs irradiation Control vs irrad & anneal @ 440oR Control vs irrad & anneal @ 540oR Irrad vs irrad & anneal @ 440oR Irrad vs irrad & anneal @ 540oR Irrad & anneal @ 440oR vs irrad & anneal @ 540oR			
Al 7039-T61, as welded	Control vs irradiated Control vs irrad & anneal @ 440oR Control vs irrad & anneal @ 540oR Irrad vs irrad & anneal @ 440oR Irrad vs irrad & anneal @ 540oR Irrad & anneal @ 440oR vs irrad & anneal @ 540oR			
Al 7039-T64, parent	Control vs irradiated			
Al 7039-T64, welded & treated to T61	Control vs irradiated			
Al 7039-T61, parent[b]	Control vs irradiated			
Al 7039-T61, as welded[b]	Control vs irradiated			

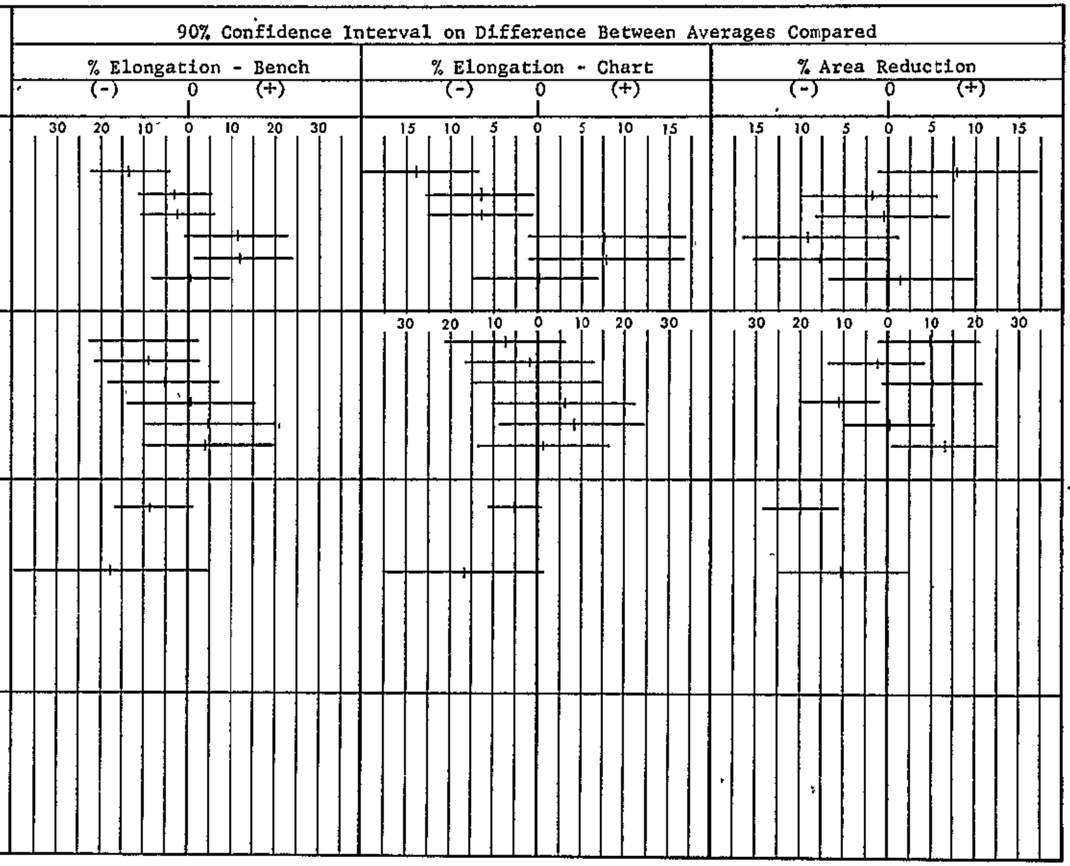


[a]Comparison is always second condition compared to the first condition.

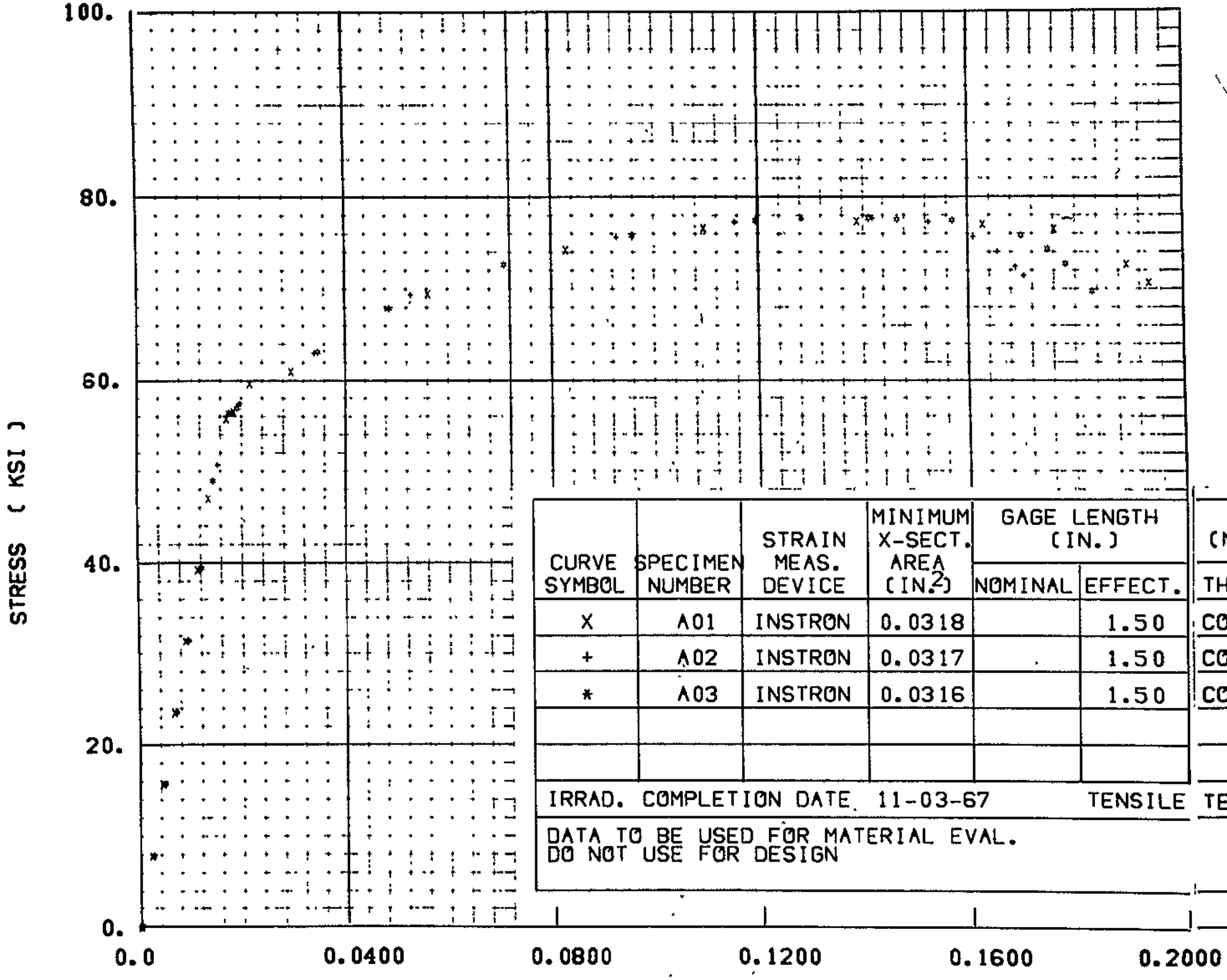
[b]Flat tensile specimens; all others round specimens.

Table 4-8 (Cont'd)

Material	Specimen Data Compared[a]
Al 7039-T61, parent	Control vs irradiated
	Control vs irrad & anneal @ 440°R
	Control vs irrad & anneal @ 540°R
	Irrad vs irrad & anneal @ 440°R
	Irrad vs irrad & anneal @ 540°R
	Irrad & anneal @ 440°R vs irrad & anneal @ 540°R
Al 7039-T61, as welded	Control vs irradiated
	Control vs irrad & anneal @ 440°R
	Control vs irrad & anneal @ 540°R
	Irrad vs irrad & anneal @ 440°R
	Irrad vs irrad & anneal @ 540°R
	Irrad & anneal @ 440°R vs irrad & anneal @ 540°R
Al 7039-T64, parent	Control vs irradiated
Al 7039-T64, welded & treated to T61	Control vs irradiated



[a] Comparison is always second condition compared to the first condition.



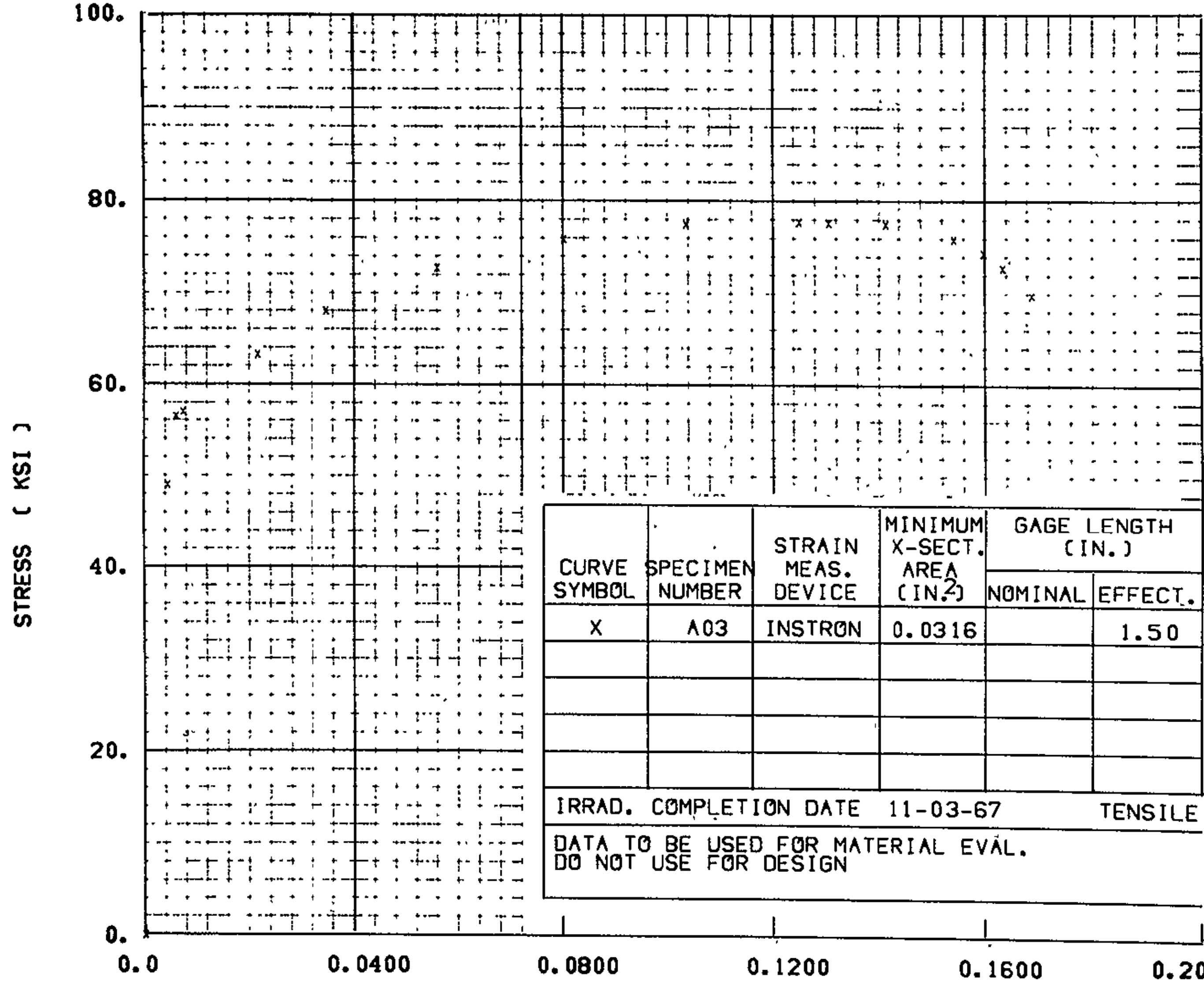
CURVE SYMBOL	SPECIMEN NUMBER	STRAIN MEAS. DEVICE	MINIMUM X-SECT. AREA ($IN.^2$)	GAGE LENGTH (IN.) NOMINAL	GAGE LENGTH (IN.) EFFECT.	FLUENCE ($NEUTRONS/CM^2$) THERMAL	FLUENCE ($NEUTRONS/CM^2$) FAST	GAMMA DOSE (ERGS/GM(C))
X	A01	INSTRON	0.0318		1.50	CONT		
+	A02	INSTRON	0.0317		1.50	CONT		
*	A03	INSTRON	0.0316		1.50	CONT		

IRRAD. COMPLETION DATE 11-03-67 TENSILE TEST DATE DEC. 67

DATA TO BE USED FOR MATERIAL EVAL.
DO NOT USE FOR DESIGN

FIGURE 4-1 STRESS-STRAIN CURVES FOR AL 7039-T61 PARENT
AT 140 R. CONTROLS

NPC 26,775



CURVE SYMBOL	SPECIMEN NUMBER	STRAIN MEAS. DEVICE	MINIMUM X-SECT. AREA ($IN.^2$)	GAGE LENGTH (IN.) NOMINAL	GAGE LENGTH (IN.) EFFECT.	FLUENCE (NEUTRONS/CM^2) THERMAL	FLUENCE (NEUTRONS/CM^2) FAST	GAMMA DOSE (ERGS/GM(C))
X	A03	INSTRON	0.0316		1.50	CONT		

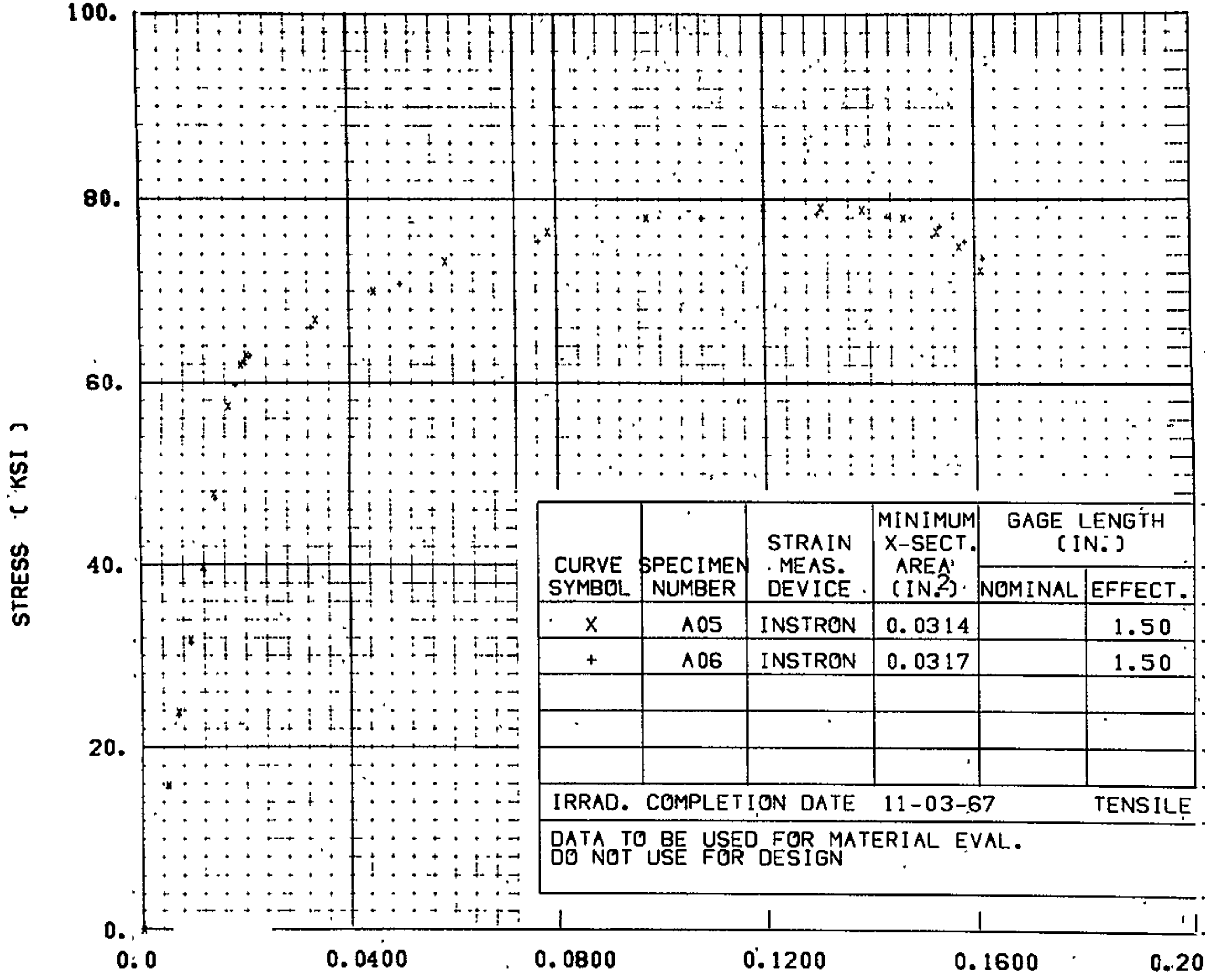
IRRAD. COMPLETION DATE 11-03-67 TENSILE TEST DATE DEC. 67

DATA TO BE USED FOR MATERIAL EVAL.
DO NOT USE FOR DESIGN

STRAIN(IN./IN. OF GAGE LENGTH)(BASED ON HANDBOOK MODULUS)

FIGURE 4-2 STRESS-STRAIN CURVE FOR AL 7039-T61 PARENT FITTED TO HANDBOOK MODULUS. CONTROL

NPC 26,776



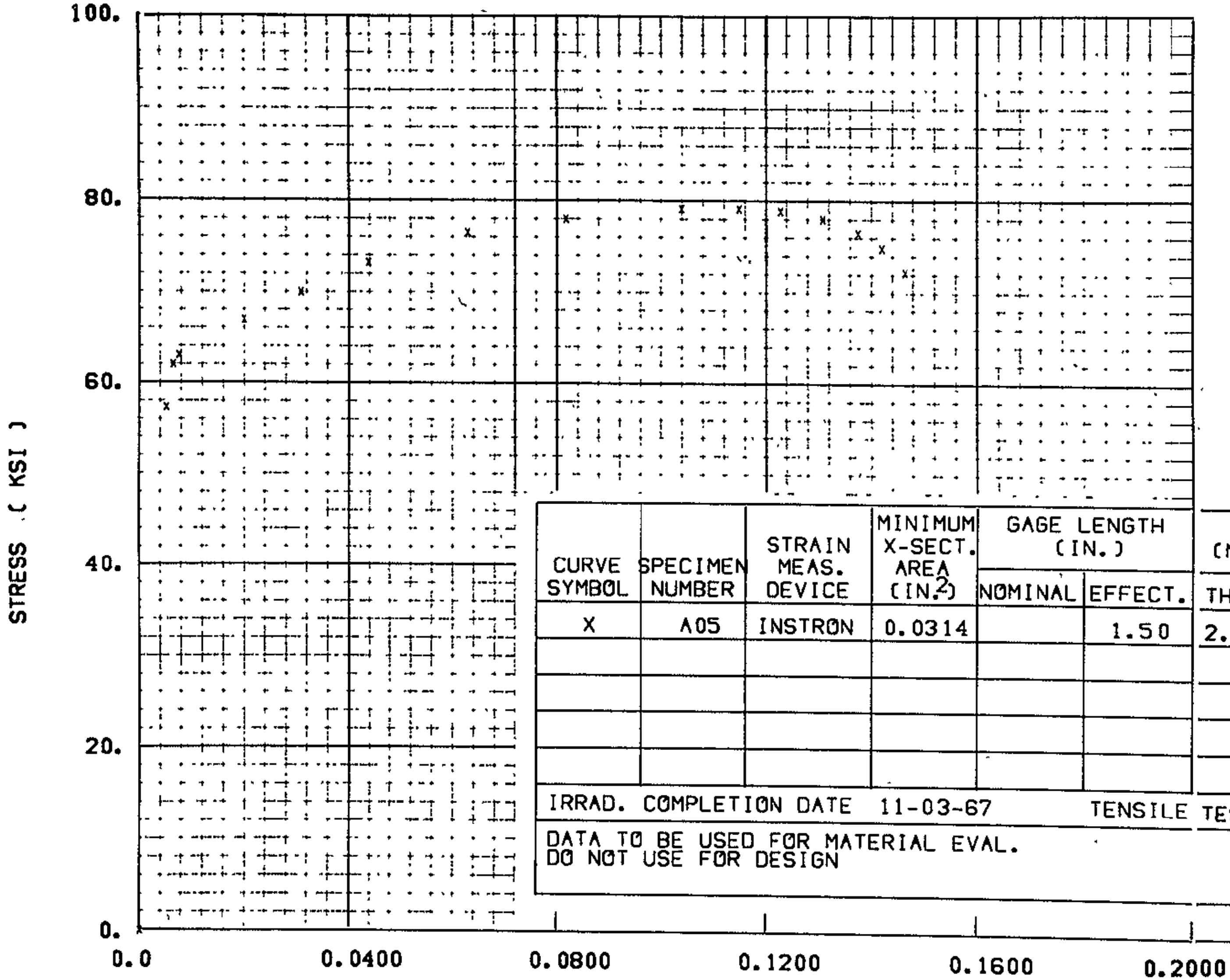
CURVE SYMBOL	SPECIMEN NUMBER	STRAIN MEAS. DEVICE	MINIMUM X-SECT. AREA (IN.^{2})	GAGE LENGTH (IN.) NOMINAL	GAGE LENGTH (IN.) EFFECT.	FLUENCE (NEUTRONS/CM^2) THERMAL	FLUENCE (NEUTRONS/CM^2) FAST	GAMMA DOSE (ERGS/GM(C))
X	A05	INSTRON	0.0314		1.50	2.4+16	8.7+16	1.1+11
+	A06	INSTRON	0.0317		1.50	2.4+16	9.1+16	1.2+11

IRRAD. COMPLETION DATE 11-03-67 TENSILE TEST DATE DEC. 67

DATA TO BE USED FOR MATERIAL EVAL.
DO NOT USE FOR DESIGN

FIGURE 4-3 STRESS-STRAIN CURVES FOR AL 7039-T61 PARENT AT 140 R. IRRADIATED IN LN

NPC 26,777.



CURVE SYMBOL	SPECIMEN NUMBER	STRAIN MEAS. DEVICE	MINIMUM X-SECT. AREA (IN.^{2})	GAGE LENGTH (IN.) NOMINAL	GAGE LENGTH (IN.) EFFECT.	FLUENCE (NEUTRONS/CM^2) THERMAL	FLUENCE (NEUTRONS/CM^2) FAST	GAMMA DOSE (ERGS/GM(C))
X	A05	INSTRON	0.0314		1.50	2.4+16	8.7+16	1.1+11

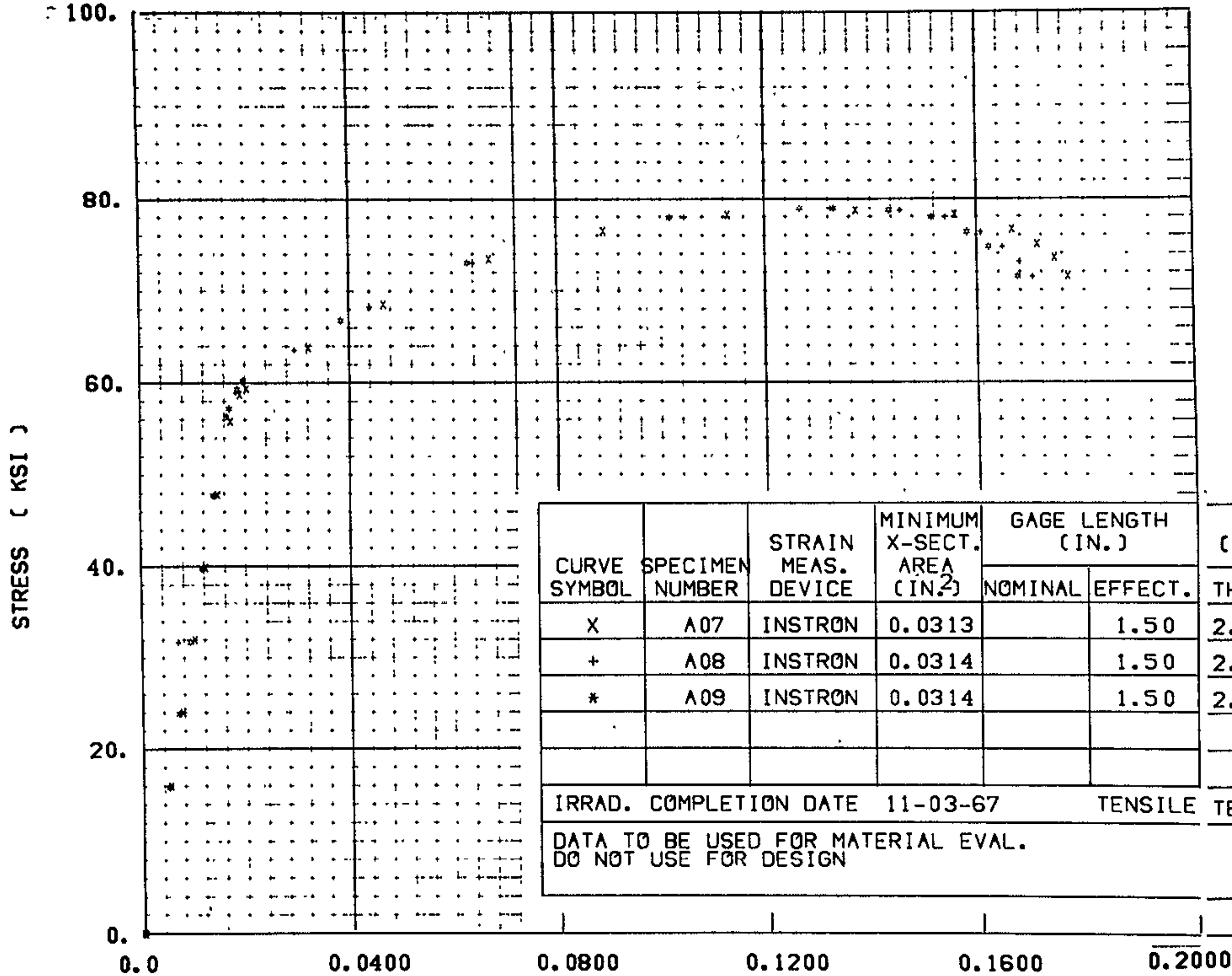
IRRAD. COMPLETION DATE 11-03-67 TENSILE TEST DATE DEC. 67

DATA TO BE USED FOR MATERIAL EVAL.
DO NOT USE FOR DESIGN

STRAIN(IN./IN. OF GAGE LENGTH)(BASED ON HANDBOOK MODULUS)

FIGURE 4-4 STRESS-STRAIN CURVE FOR AL 7039-T61 PARENT FITTED TO HANDBOOK MODULUS. IRRADIATED IN LN

NPC 26,778



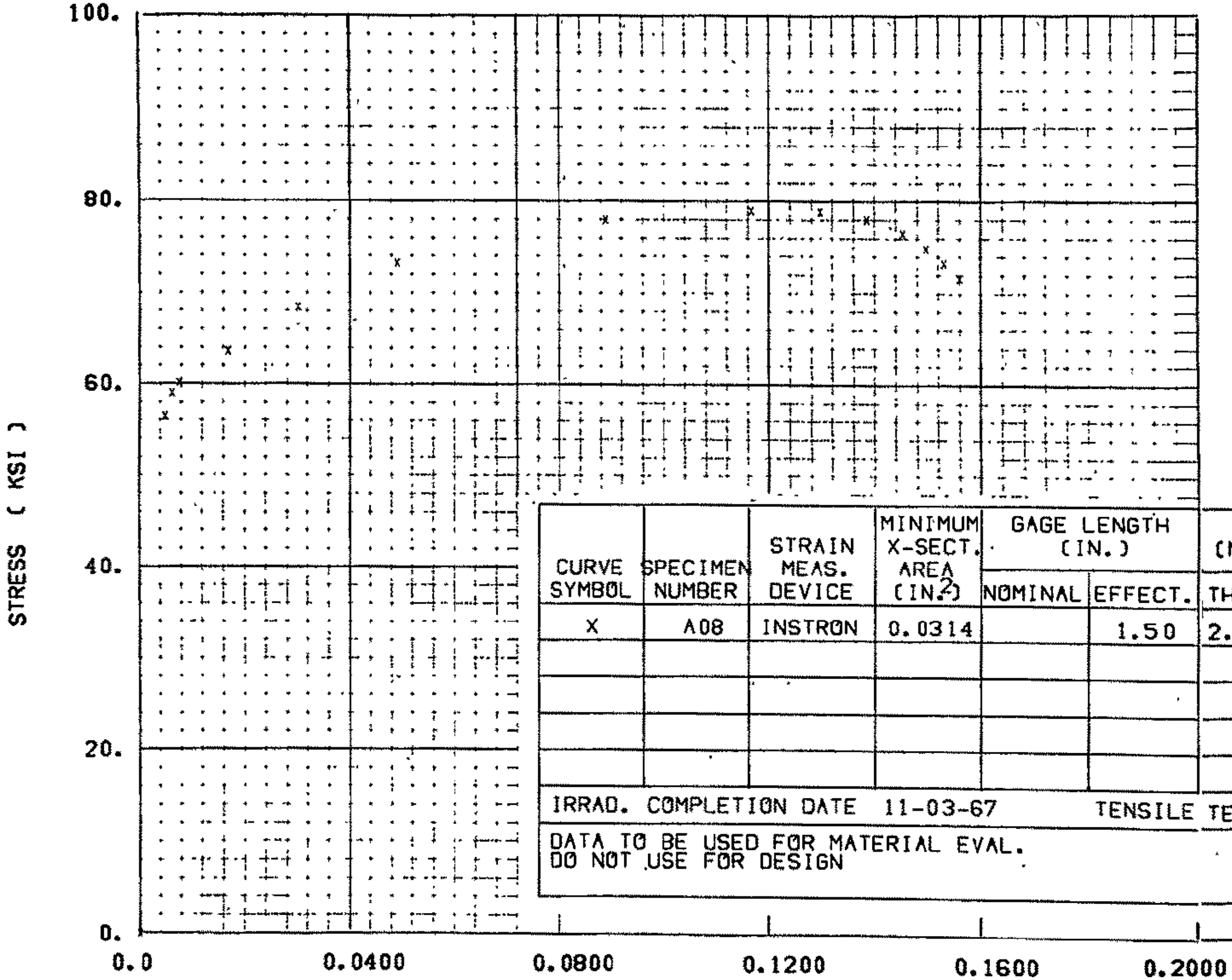
CURVE SYMBOL	SPECIMEN NUMBER	STRAIN MEAS. DEVICE	MINIMUM X-SECT. AREA (IN.^{2})	GAGE LENGTH (IN.) NOMINAL	EFFECT.	FLUENCE (NEUTRONS/CM^2) THERMAL	FAST	GAMMA DOSE (ERGS/GM(C))
X	A07	INSTRON	0.0313		1.50	2.0+16	8.4+16	1.1+11
+	A08	INSTRON	0.0314		1.50	2.0+16	1.0+17	1.3+11
*	A09	INSTRON	0.0314		1.50	2.0+16	1.2+17	1.5+11

IRRAD. COMPLETION DATE 11-03-67 TENSILE TEST DATE DEC. 67

DATA TO BE USED FOR MATERIAL EVAL.
DO NOT USE FOR DESIGN

FIGURE 4-5 STRESS-STRAIN CURVES FOR AL 7039-T61 PARENT AT 140 R. IRRADIATED IN LN. ANNEALED 1 H AT 440 R

NPC 26,779



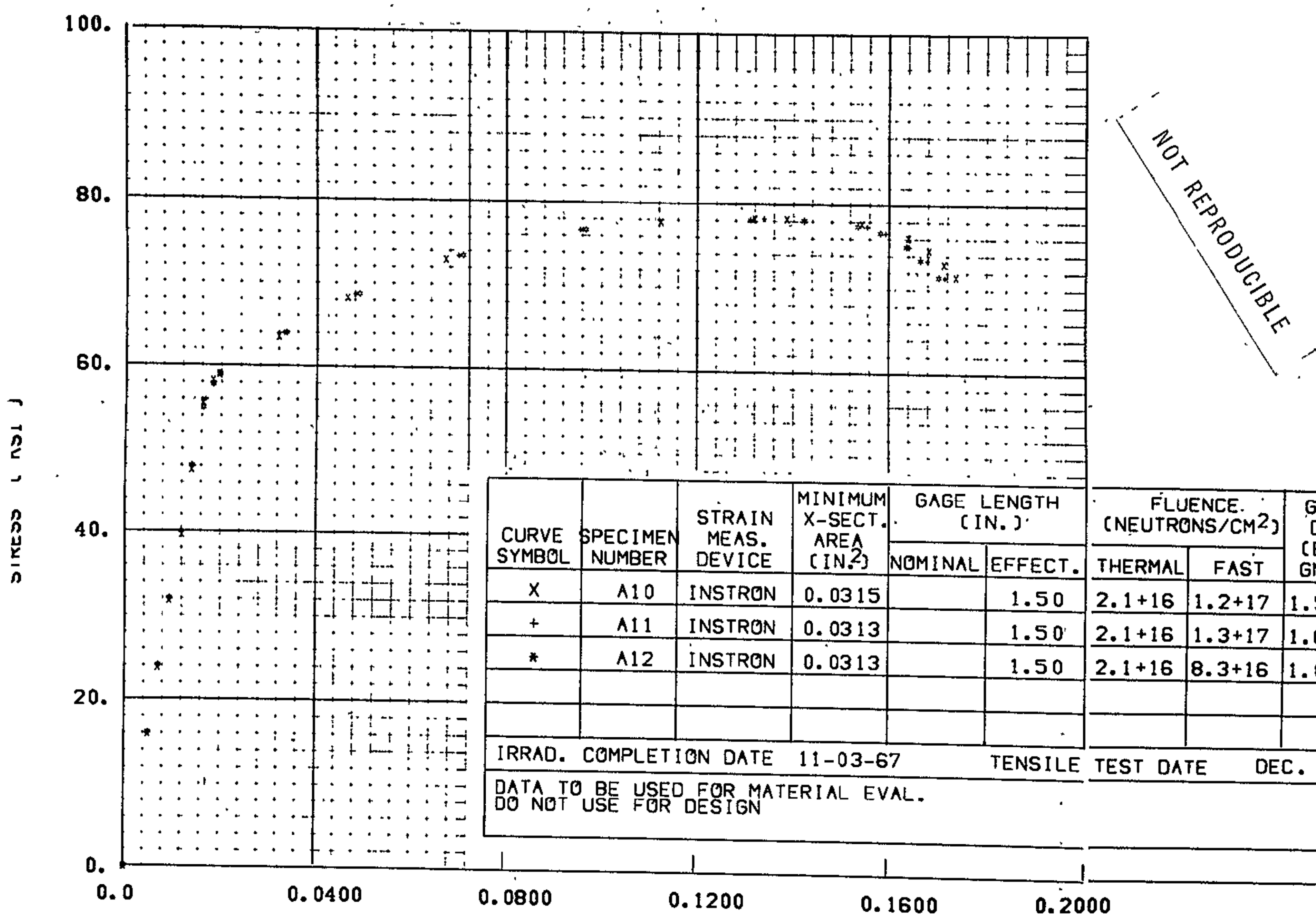
CURVE SYMBOL	SPECIMEN NUMBER	STRAIN MEAS. DEVICE	MINIMUM X-SECT. AREA (IN.^{2})	GAGE LENGTH (IN.) NOMINAL	GAGE LENGTH (IN.) EFFECT.	FLUENCE (NEUTRONS/CM^2) THERMAL	FLUENCE (NEUTRONS/CM^2) FAST	GAMMA DOSE (ERGS/GM(C))
X	A08	INSTRON	0.0314		1.50	2.0+16	1.0+17	1.3+11

IRRAD. COMPLETION DATE 11-03-67 TENSILE TEST DATE DEC. 67

DATA TO BE USED FOR MATERIAL EVAL.
DO NOT USE FOR DESIGN

STRAIN(IN./IN. OF GAGE LENGTH)(BASED ON HANDBOOK MODULUS)

FIGURE 4-6 STRESS-STRAIN CURVE FOR AL 7039-T61 PARENT FITTED TO HANDBOOK MODULUS. IRRAD IN LN. ANNEALED AT 440 R



CURVE SYMBOL	SPECIMEN NUMBER	STRAIN MEAS. DEVICE	MINIMUM X-SECT. AREA (IN.^{2})	GAGE LENGTH (IN.)		FLUENCE (NEUTRONS/CM^2)		GAMMA DOSE (ERGS/GM(C))
				NOMINAL	EFFECT.	THERMAL	FAST	
X	A10	INSTRON	0.0315		1.50	2.1+16	1.2+17	1.5+11
+	A11	INSTRON	0.0313		1.50	2.1+16	1.3+17	1.6+11
*	A12	INSTRON	0.0313		1.50	2.1+16	8.3+16	1.0+11

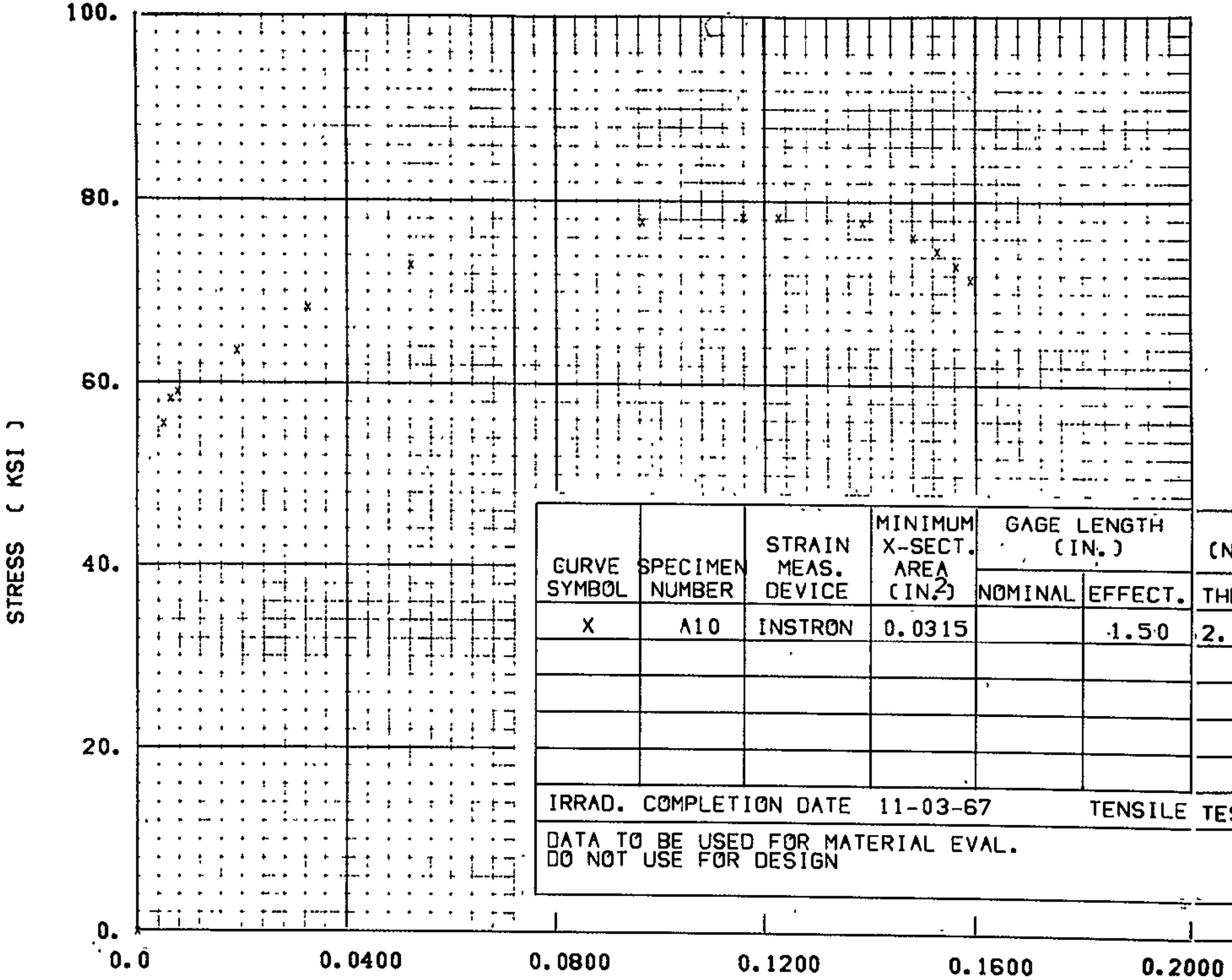
IRRAD. COMPLETION DATE 11-03-67 TENSILE TEST DATE DEC. 67

DATA TO BE USED FOR MATERIAL EVAL.
DO NOT USE FOR DESIGN

STRAIN (IN./IN. OF GAGE LENGTH)(BASED ON CROSSHEAD TRAVEL)

FIGURE 4-7 STRESS-STRAIN CURVES FOR AL 7039-T61 PARENT AT 140 R. IRRADIATED IN LN. ANNEALED 1 H AT 540 R

NPC 26,781



CURVE SYMBOL	SPECIMEN NUMBER	STRAIN MEAS. DEVICE	MINIMUM X-SECT. AREA (IN.^{2})	GAGE LENGTH (IN.) NOMINAL	GAGE LENGTH (IN.) EFFECT.	FLUENCE (NEUTRONS/CM^2) THERMAL	FLUENCE (NEUTRONS/CM^2) FAST	GAMMA DOSE (ERGS/GM(C))
X	A10	INSTRON	0.0315		1.50	2.1+16	1.2+17	1.5+11

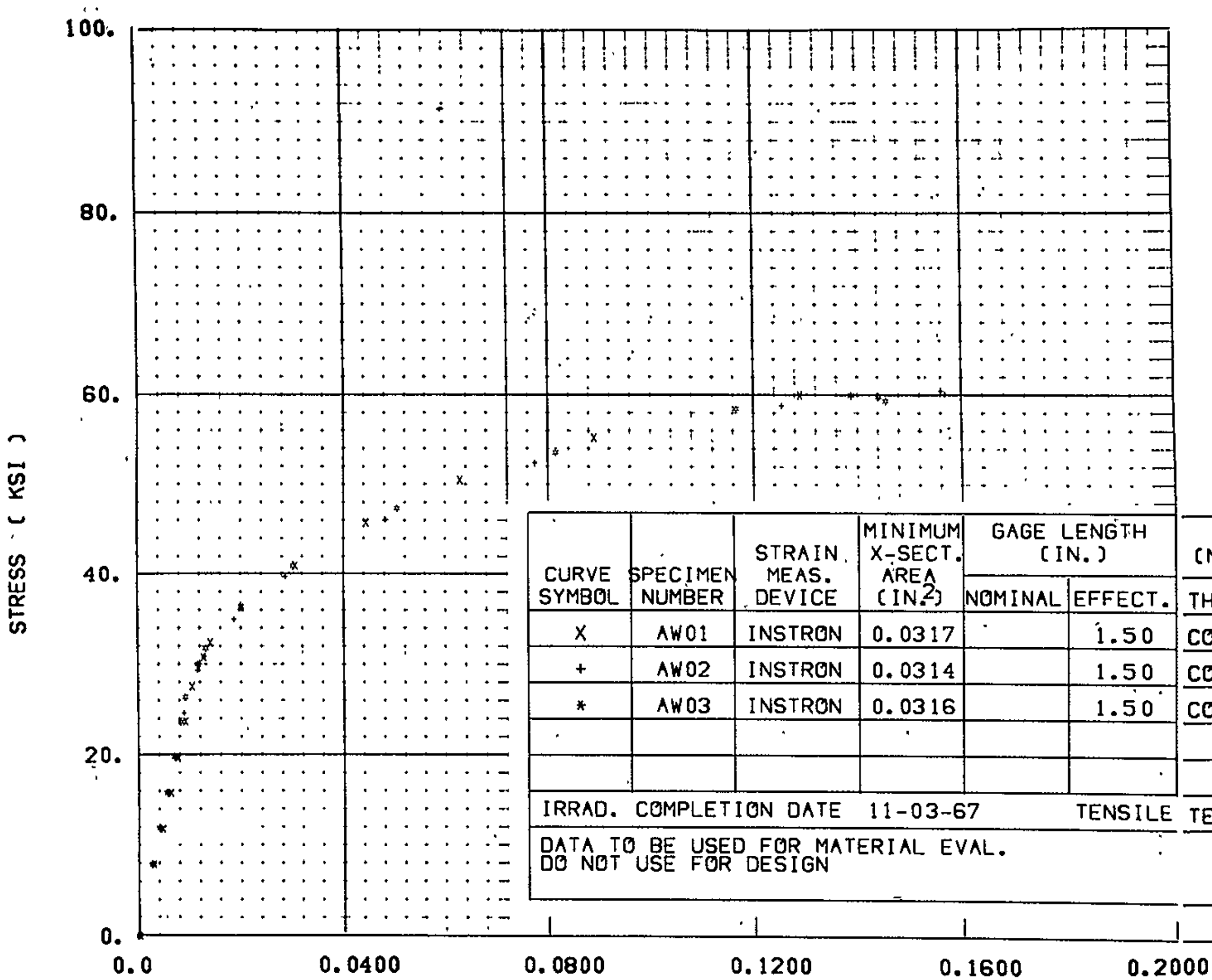
IRRAD. COMPLETION DATE 11-03-67 TENSILE TEST DATE DEC. 67

DATA TO BE USED FOR MATERIAL EVAL.
DO NOT USE FOR DESIGN

STRAIN(IN./IN. OF GAGE LENGTH)(BASED ON HANDBOOK MODULUS)

FIGURE 4-8 STRESS-STRAIN CURVE FOR AL 7039-T61 PARENT
FITTED TO HANDBOOK MODULUS. IRRAD IN LN. ANNEALED AT 540 R

NPC 26,782



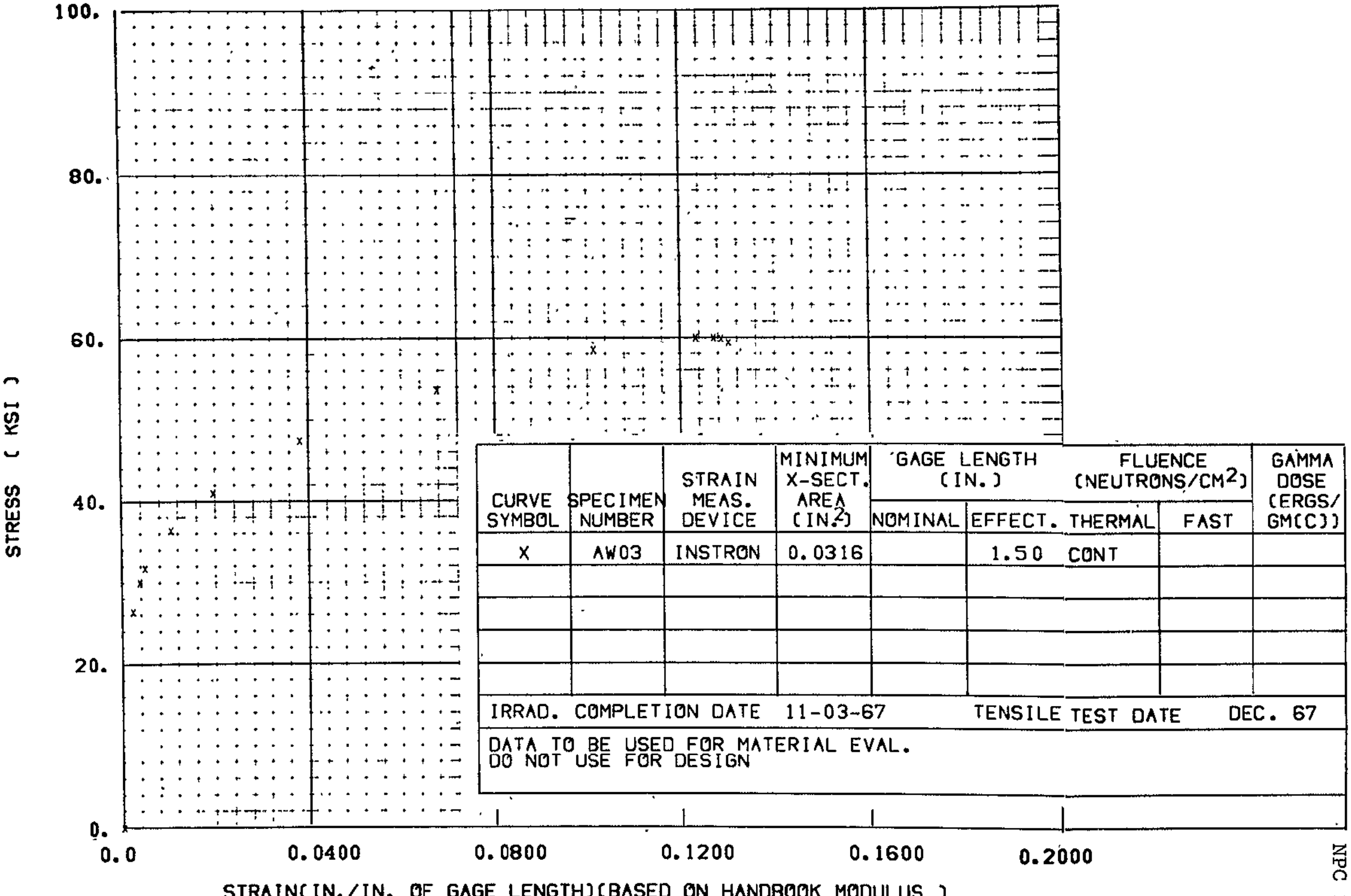
CURVE SYMBOL	SPECIMEN NUMBER	STRAIN MEAS. DEVICE	MINIMUM X-SECT. AREA (IN.^{2})	GAGE LENGTH (IN.) NOMINAL	GAGE LENGTH (IN.) EFFECT.	FLUENCE (NEUTRONS/CM^2) THERMAL	FLUENCE (NEUTRONS/CM^2) FAST	GAMMA DOSE (ERGS/GM(C))
X	AW01	INSTRON	0.0317		1.50	CONT		
+	AW02	INSTRON	0.0314		1.50	CONT		
*	AW03	INSTRON	0.0316		1.50	CONT		

IRRAD. COMPLETION DATE 11-03-67 TENSILE TEST DATE DEC. 67

DATA TO BE USED FOR MATERIAL EVAL.
DO NOT USE FOR DESIGN

FIGURE 4-9 STRESS-STRAIN CURVES FOR AS-WELDED AL 7039-T61 AT 140 R. CONTROLS

NPC 26,783



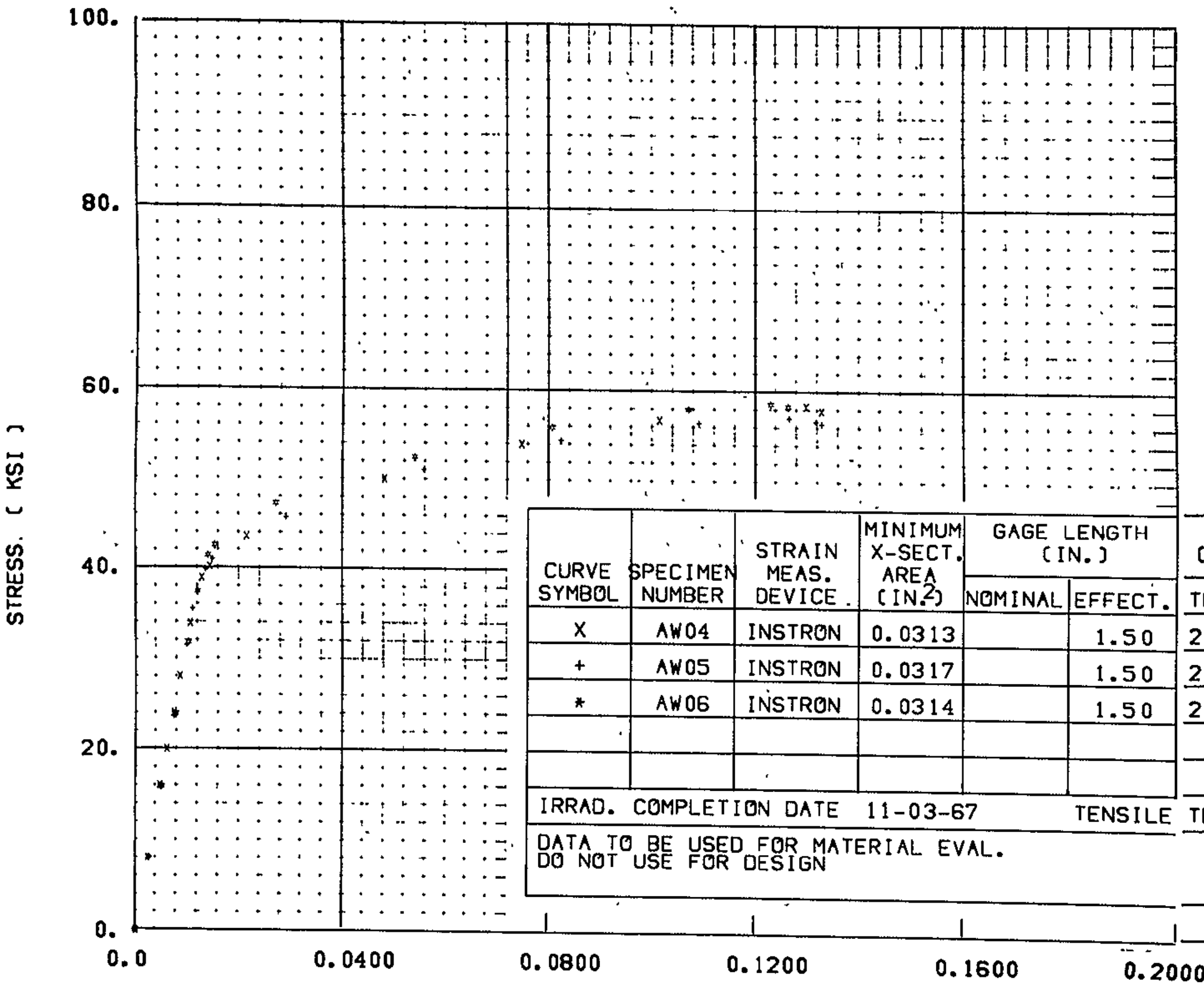
CURVE SYMBOL	SPECIMEN NUMBER	STRAIN MEAS. DEVICE	MINIMUM X-SECT. AREA (IN.2)	GAGE LENGTH (IN.)		FLUENCE (NEUTRONS/CM2)		GAMMA DOSE (ERGS/GM(C))
				NOMINAL	EFFECT.	THERMAL	FAST	
X	AW03	INSTRON	0.0316		1.50	CONT		

IRRAD. COMPLETION DATE 11-03-67 TENSILE TEST DATE DEC. 67

DATA TO BE USED FOR MATERIAL EVAL.
DO NOT USE FOR DESIGN

FIGURE 4-10 STRESS-STRAIN CURVE FOR AS-WELDED AL 7039-T61 FITTED TO HANDBOOK MODULUS. CONTROL

NPC 26,784

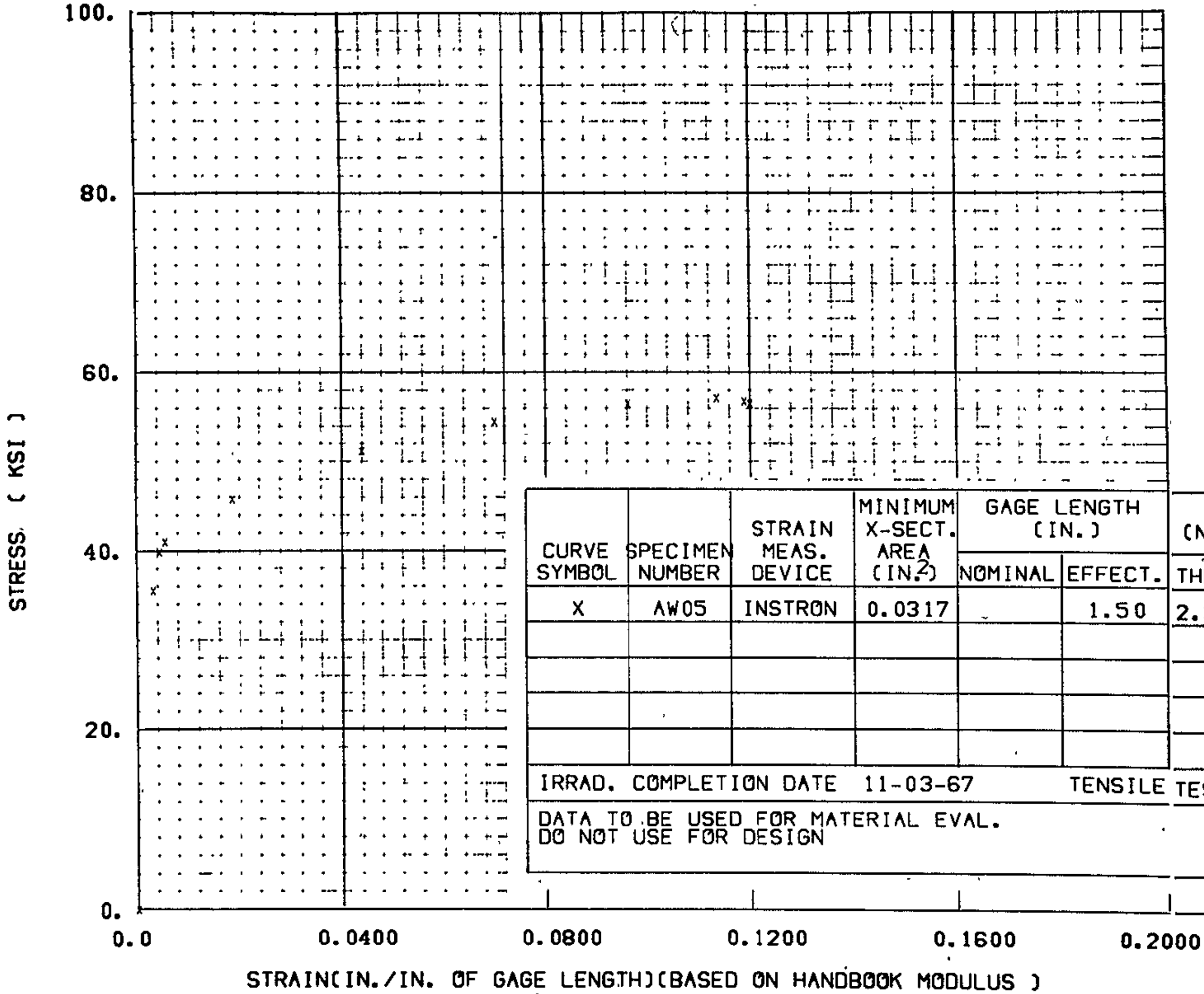


CURVE SYMBOL	SPECIMEN NUMBER	STRAIN MEAS. DEVICE	MINIMUM X-SECT. AREA (IN.^{2})	GAGE LENGTH (IN.) NOMINAL	GAGE LENGTH (IN.) EFFECT.	FLUENCE (NEUTRONS/CM^2) THERMAL	FLUENCE (NEUTRONS/CM^2) FAST	GAMMA DOSE (ERGS/GM(C))
X	AW04	INSTRON	0.0313		1.50	2.3+16	8.5+16	1.1+11
+	AW05	INSTRON	0.0317		1.50	2.3+16	9.5+16	1.2+11
*	AW06	INSTRON	0.0314		1.50	2.3+16	1.2+17	1.4+11

IRRAD. COMPLETION DATE 11-03-67 TENSILE TEST DATE DEC. 67

DATA TO BE USED FOR MATERIAL EVAL.
DO NOT USE FOR DESIGN

FIGURE 4-11 STRESS-STRAIN CURVES FOR AS-WELDED AL 7039-T61 AT 140 R. IRRADIATED IN LN



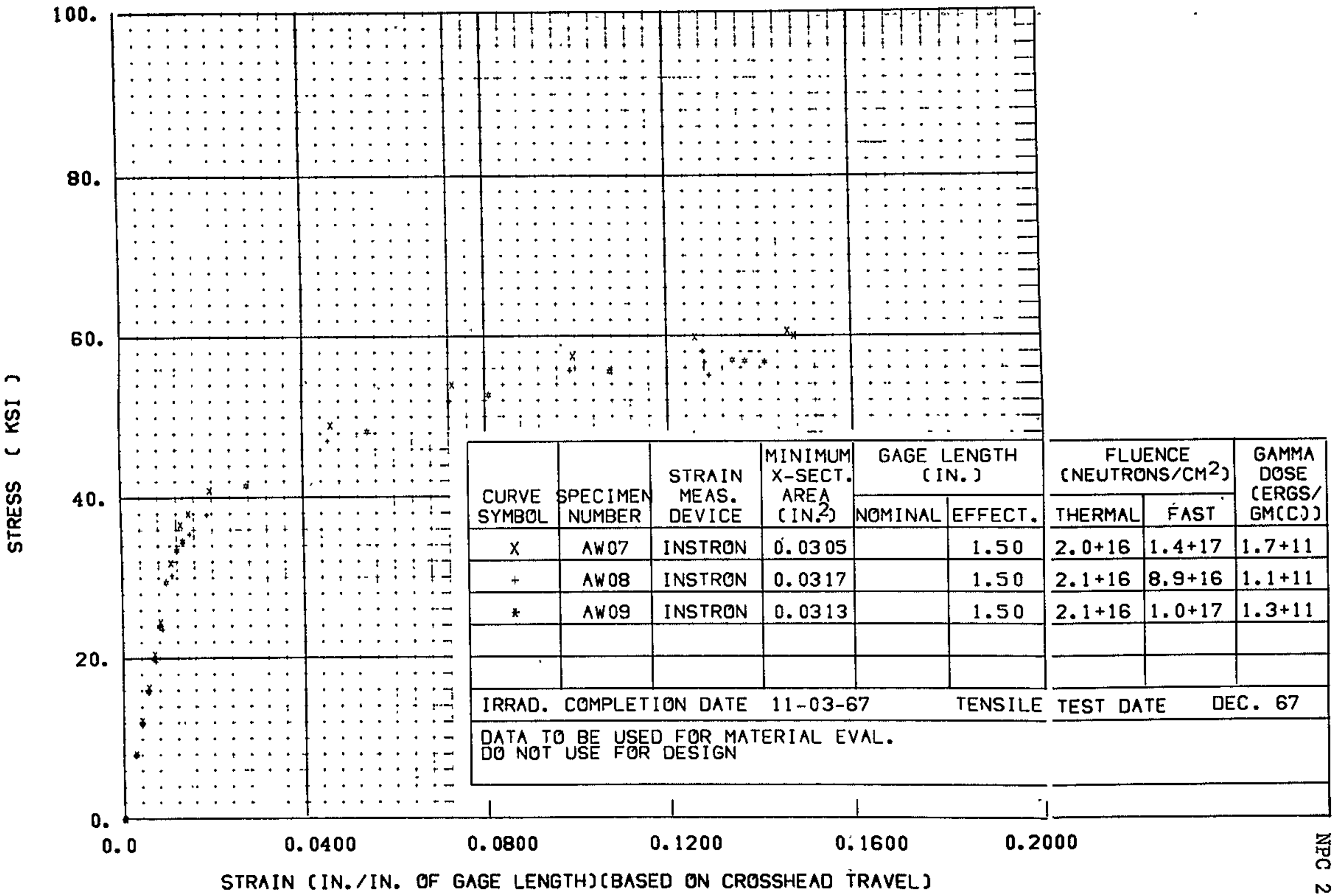
CURVE SYMBOL	SPECIMEN NUMBER	STRAIN MEAS. DEVICE	MINIMUM X-SECT. AREA (IN.^{2})	GAGE LENGTH (IN.) NOMINAL	GAGE LENGTH (IN.) EFFECT.	FLUENCE (NEUTRONS/CM^2) THERMAL	FLUENCE (NEUTRONS/CM^2) FAST	GAMMA DOSE (ERGS/GM(C))
X	AW05	INSTRON	0.0317		1.50	2.3+16	9.5+16	1.2+11

IRRAD. COMPLETION DATE 11-03-67 TENSILE TEST DATE DEC. 67

DATA TO BE USED FOR MATERIAL EVAL.
DO NOT USE FOR DESIGN

FIGURE 4-12 STRESS-STRAIN CURVE FOR AS-WELDED AL 7039-T61 FITTED TO HANDBOOK MODULUS. IRRADIATED IN LN

NPC 26,786



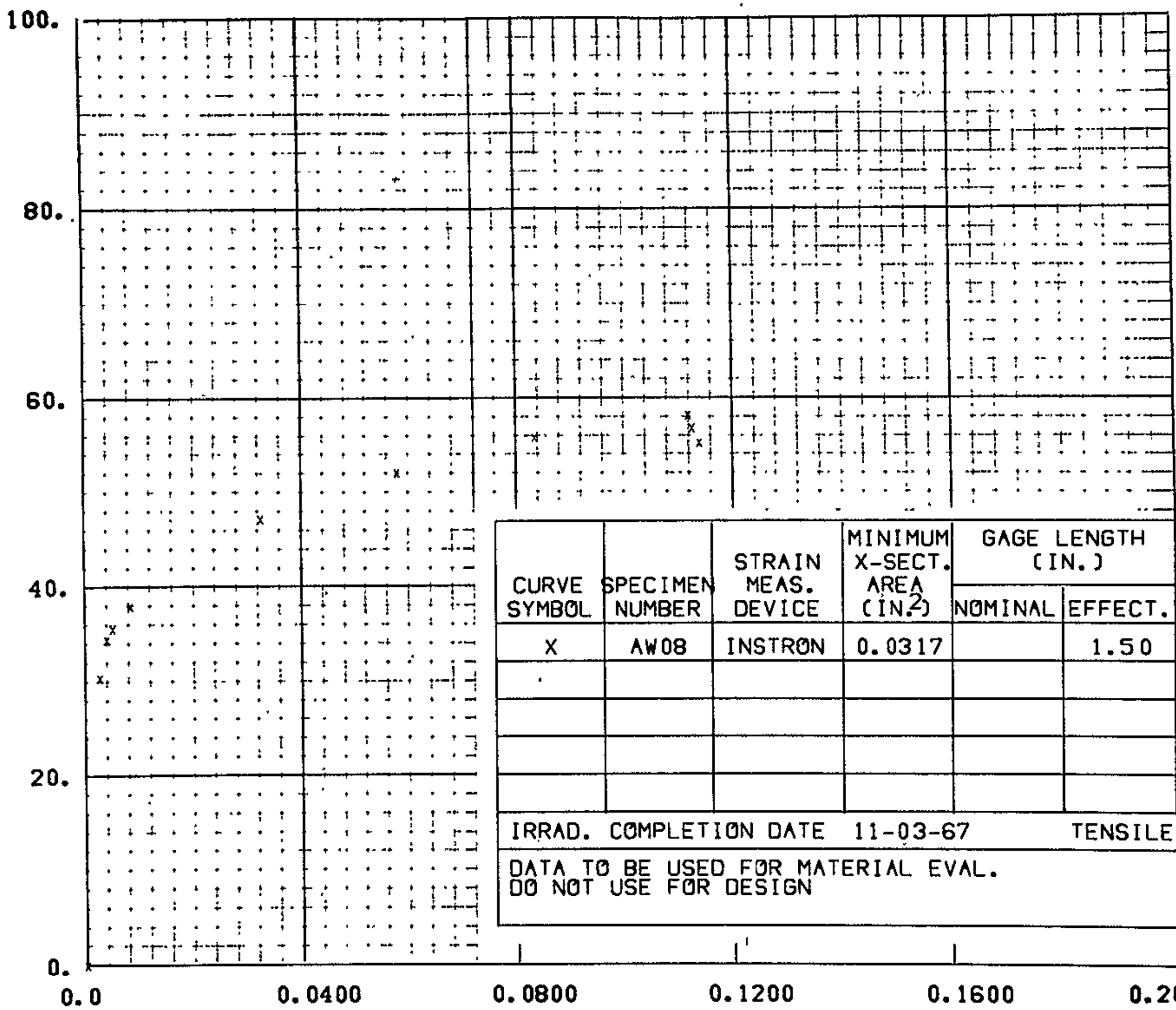
CURVE SYMBOL	SPECIMEN NUMBER	STRAIN MEAS. DEVICE	MINIMUM X-SECT. AREA (IN.^{2})	GAGE LENGTH (IN.)		FLUENCE (NEUTRONS/CM^2)		GAMMA DOSE (ERGS/GM(C))
				NOMINAL	EFFECT.	THERMAL	FAST	
X	AW07	INSTRON	0.0305		1.50	2.0+16	1.4+17	1.7+11
+	AW08	INSTRON	0.0317		1.50	2.1+16	8.9+16	1.1+11
*	AW09	INSTRON	0.0313		1.50	2.1+16	1.0+17	1.3+11

IRRAD. COMPLETION DATE 11-03-67 TENSILE TEST DATE DEC. 67

DATA TO BE USED FOR MATERIAL EVAL.
DO NOT USE FOR DESIGN

FIGURE 4-13 STRESS-STRAIN CURVES FOR AS-WELDED AL 7039-T61 AT 140 R. IRRADIATED IN LN, ANNEALED 1 H AT 440 R

NPC 26,787



CURVE SYMBOL	SPECIMEN NUMBER	STRAIN MEAS. DEVICE	MINIMUM X-SECT. AREA (IN.^{2})	GAGE LENGTH (IN.) NOMINAL	GAGE LENGTH (IN.) EFFECT.	FLUENCE (NEUTRONS/CM^2) THERMAL	FLUENCE (NEUTRONS/CM^2) FAST	GAMMA DOSE (ERGS/GM(C))
X	AW08	INSTRON	0.0317		1.50	2.1+16	8.9+16	1.1+11

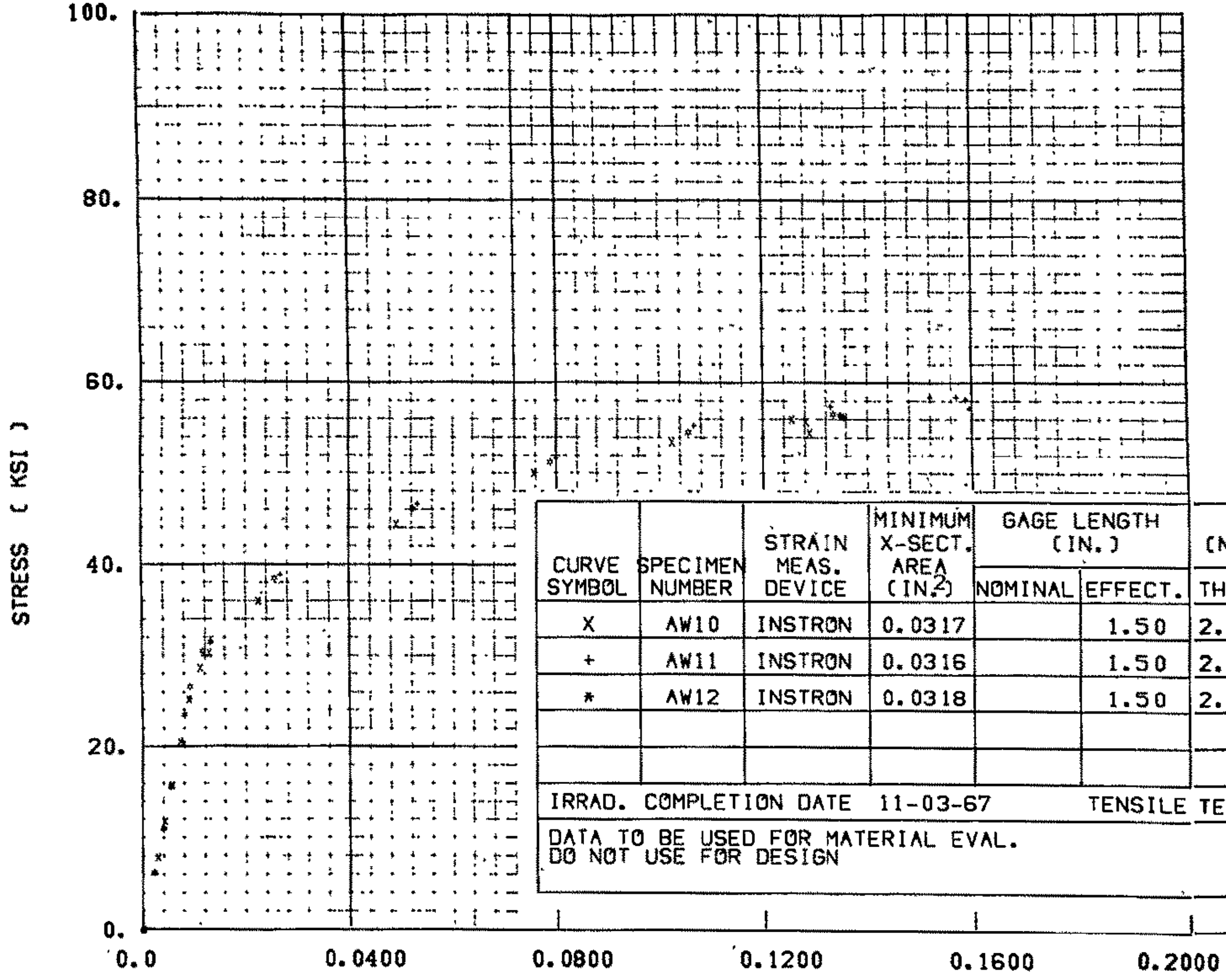
IRRAD. COMPLETION DATE 11-03-67 TENSILE TEST DATE DEC. 67

DATA TO BE USED FOR MATERIAL EVAL.
DO NOT USE FOR DESIGN

STRAIN(IN./IN. OF GAGE LENGTH)(BASED ON HANDBOOK MODULUS)

FIGURE 4-14 STRESS-STRAIN CURVE FOR AS-WELDED AL 7039-T61
FITTED TO HANDBOOK MODULUS. IRRAD IN LN. ANNEALED AT 440 R

NPC 26,788



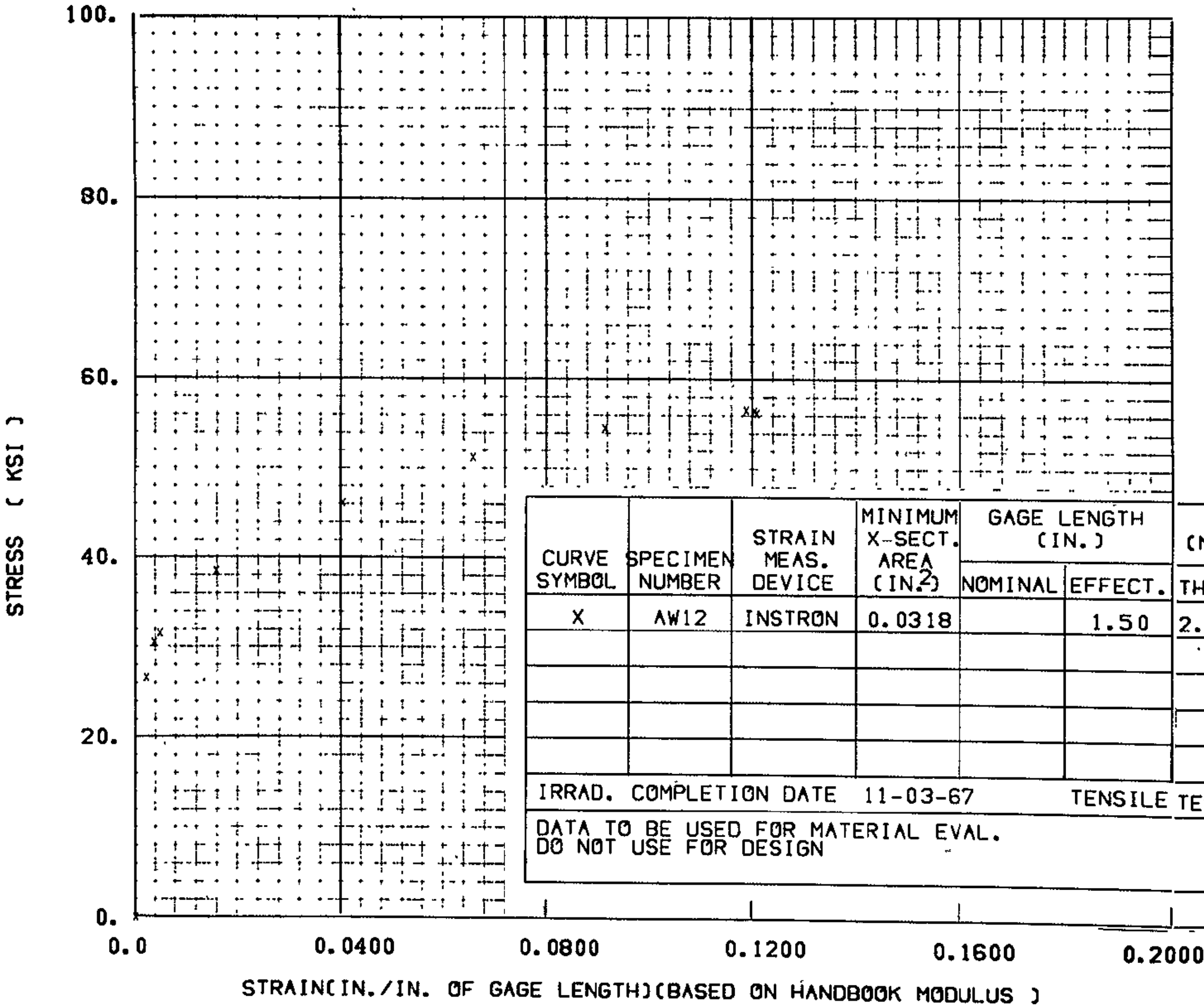
CURVE SYMBOL	SPECIMEN NUMBER	STRAIN MEAS. DEVICE	MINIMUM X-SECT. AREA (IN.2)	GAGE LENGTH (IN.)		FLUENCE (NEUTRONS/CM2)		GAMMA DOSE (ERGS/GM(C))
				NOMINAL	EFFECT.	THERMAL	FAST	
X	AW10	INSTRON	0.0317		1.50	2.2+16	9.8+16	1.2+11
+	AW11	INSTRON	0.0316		1.50	2.2+16	1.2+17	1.5+11
*	AW12	INSTRON	0.0318		1.50	2.2+16	1.2+17	1.5+11

IRRAD. COMPLETION DATE 11-03-67 TENSILE TEST DATE DEC. 67

DATA TO BE USED FOR MATERIAL EVAL.
DO NOT USE FOR DESIGN

FIGURE 4-15 STRESS-STRAIN CURVES FOR AS-WELDED AL 7039-T61
AT 140 R. IRRADIATED IN LN, ANNEALED 1 H AT 540 R

NPC 26,789

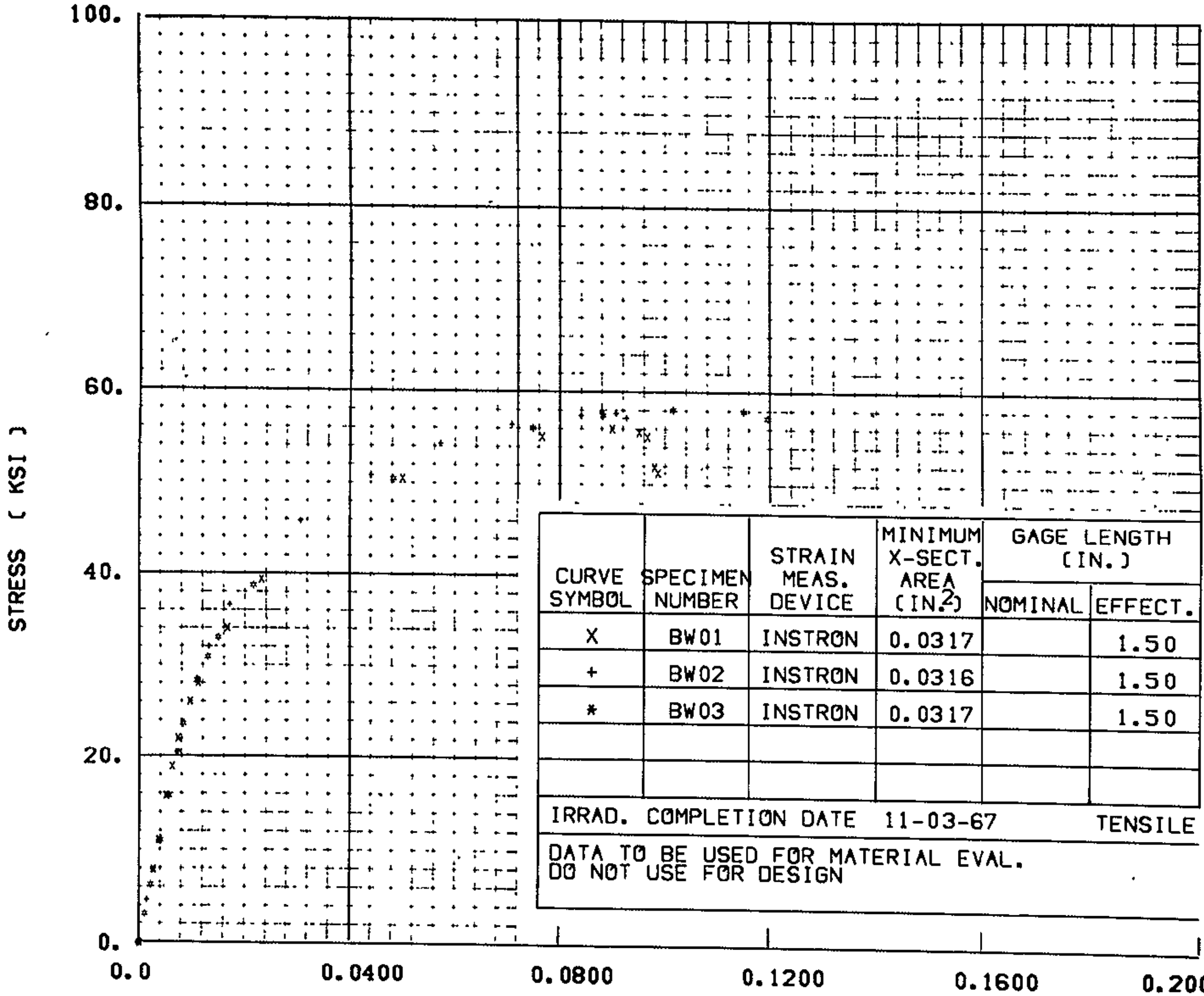


CURVE SYMBOL	SPECIMEN NUMBER	STRAIN MEAS. DEVICE	MINIMUM X-SECT. AREA (IN.^{2})	GAGE LENGTH (IN.)		FLUENCE (NEUTRONS/CM^2)		GAMMA DOSE (ERGS/GM(C))
				NOMINAL	EFFECT.	THERMAL	FAST	
X	AW12	INSTRON	0.0318		1.50	2.2+16	2.1+16	1.5+11

IRRAD. COMPLETION DATE 11-03-67 TENSILE TEST DATE DEC. 67

DATA TO BE USED FOR MATERIAL EVAL.
DO NOT USE FOR DESIGN

FIGURE 4-16 STRESS-STRAIN CURVE FOR AS-WELDED AL 7039-T61 FITTED TO HANDBOOK MODULUS. IRRAD IN LN. ANNEALED AT 540 R



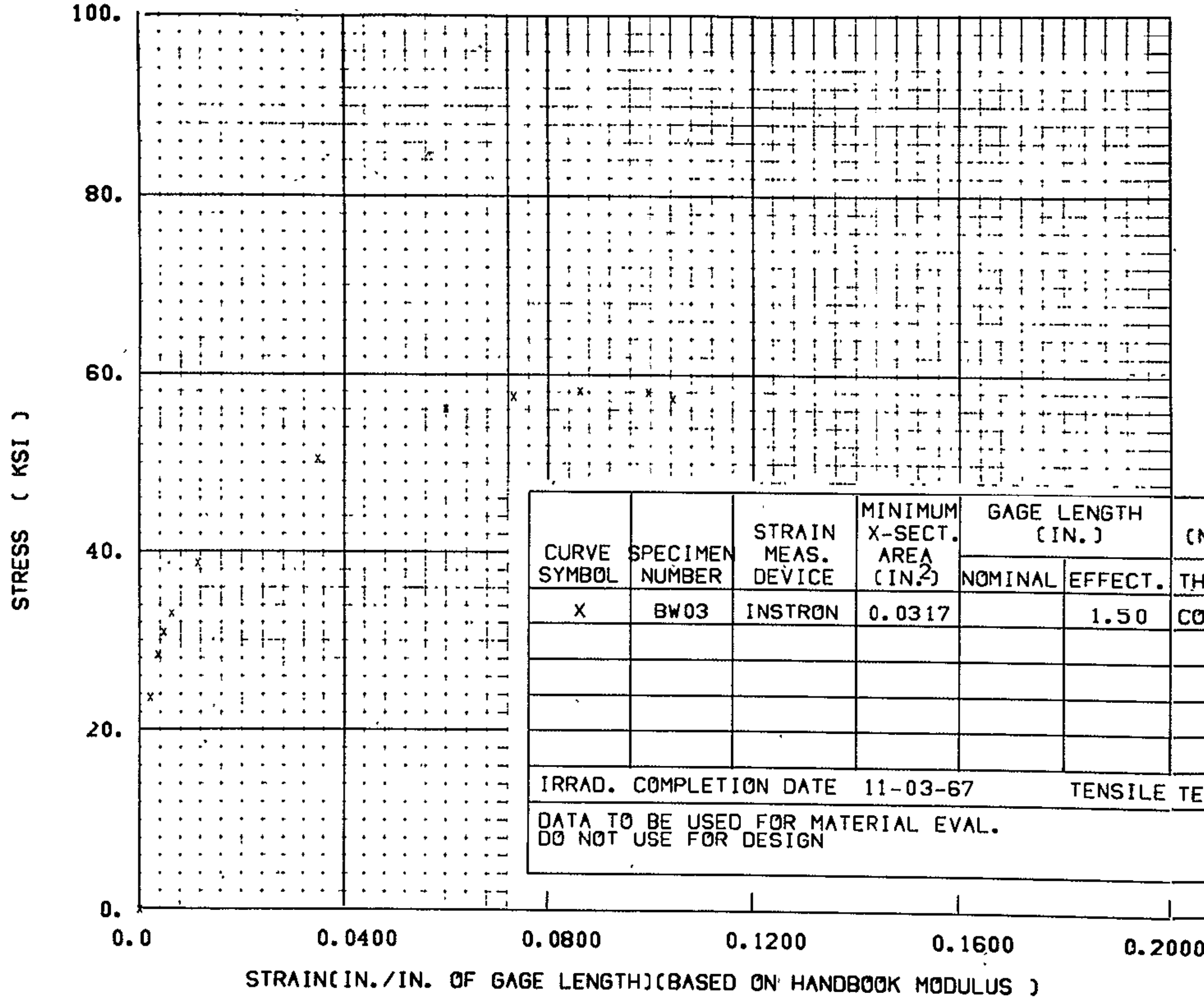
CURVE SYMBOL	SPECIMEN NUMBER	STRAIN MEAS. DEVICE	MINIMUM X-SECT. AREA ($IN.^2$)	GAGE LENGTH (IN.) NOMINAL	GAGE LENGTH (IN.) EFFECT.	FLUENCE (NEUTRONS/CM^2) THERMAL	FLUENCE (NEUTRONS/CM^2) FAST	GAMMA DOSE (ERGS/GM(C))
X	BW01	INSTRON	0.0317		1.50	CONT		
+	BW02	INSTRON	0.0316		1.50	CONT		
*	BW03	INSTRON	0.0317		1.50	CONT		

IRRAD. COMPLETION DATE 11-03-67 TENSILE TEST DATE DEC. 67

DATA TO BE USED FOR MATERIAL EVAL.
DO NOT USE FOR DESIGN

FIGURE 4-17 STRESS-STRAIN CURVES FOR AL 7039-T64, WELDED AND TREATED TO T61. AT 140 R. CONTROLS

NPC 26,791



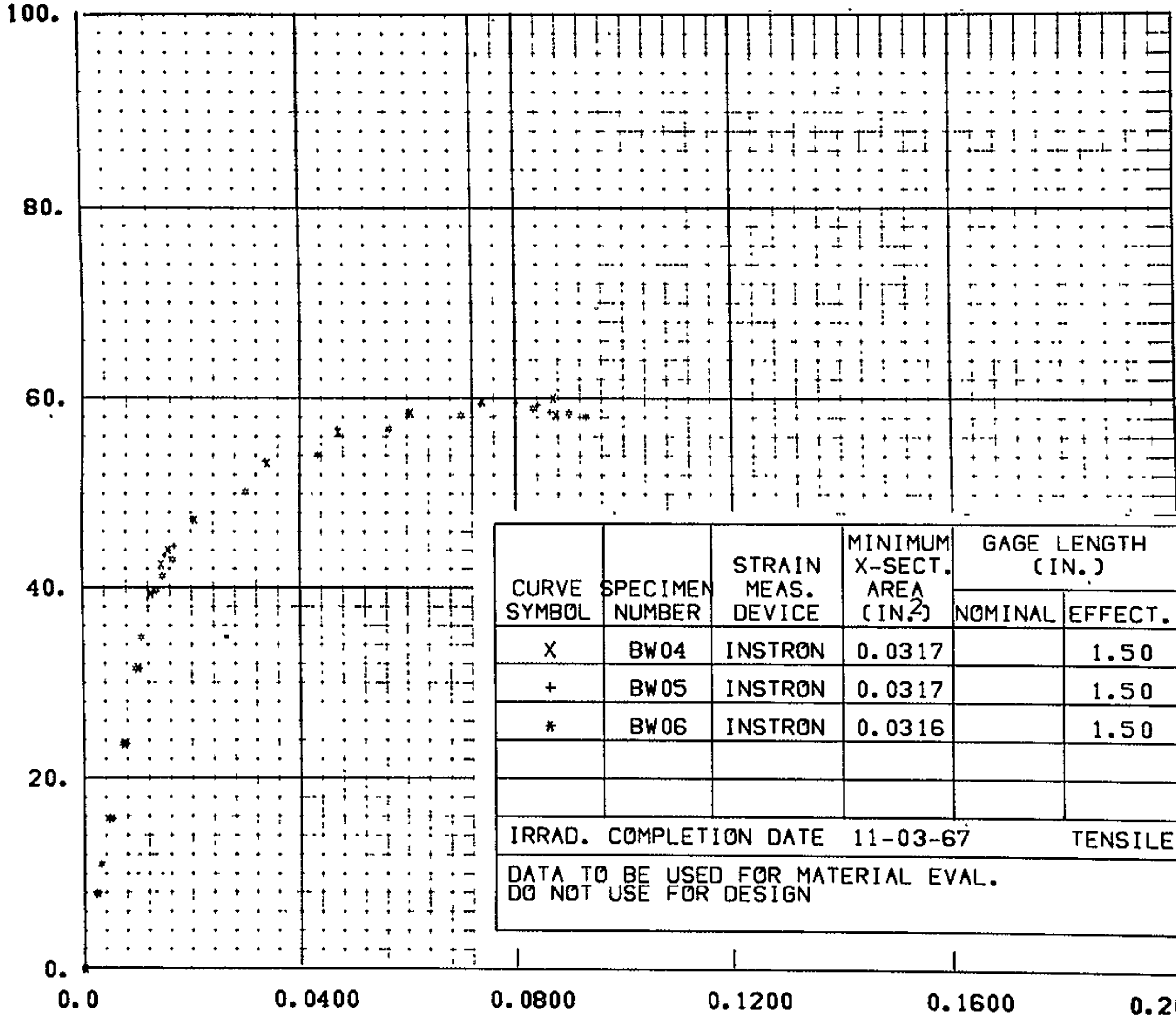
CURVE SYMBOL	SPECIMEN NUMBER	STRAIN MEAS. DEVICE	MINIMUM X-SECT. AREA (IN.^{2})	GAGE LENGTH (IN.) NOMINAL	GAGE LENGTH (IN.) EFFECT.	FLUENCE (NEUTRONS/CM^2) THERMAL	FLUENCE (NEUTRONS/CM^2) FAST	GAMMA DOSE (ERGS/GM(C))
X	BW03	INSTRON	0.0317		1.50	CONT		

IRRAD. COMPLETION DATE 11-03-67 TENSILE TEST DATE DEC. 67

DATA TO BE USED FOR MATERIAL EVAL.
DO NOT USE FOR DESIGN

FIGURE 4-18 STRESS-STRAIN CURVE FOR AL 7039-T64, WELDED AND TREATED TO T61, FITTED TO HANDBOOK MODULUS. CONTROL

NPC 26,792



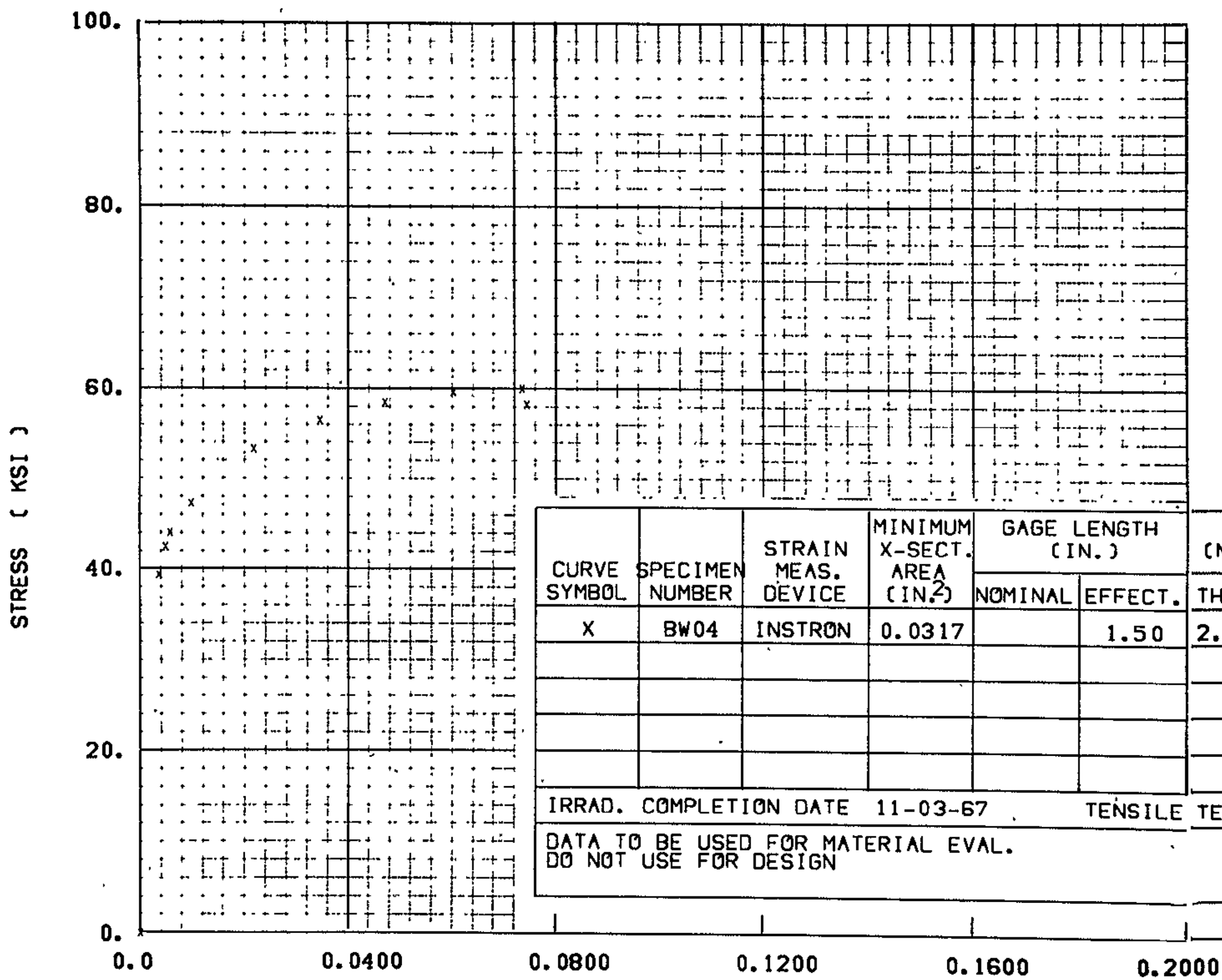
CURVE SYMBOL	SPECIMEN NUMBER	STRAIN MEAS. DEVICE	MINIMUM X-SECT. AREA (IN.^{2})	GAGE LENGTH (IN.)		FLUENCE (NEUTRONS/CM^2)		GAMMA DOSE (ERGS/GM(C))
				NOMINAL	EFFECT.	THERMAL	FAST	
X	BW04	INSTRON	0.0317		1.50	2.4+16	1.1+17	1.3+11
+	BW05	INSTRON	0.0317		1.50	2.4+16	1.1+17	1.4+11
*	BW06	INSTRON	0.0316		1.50	2.5+16	0.9+17	1.1+11

IRRAD. COMPLETION DATE 11-03-67 TENSILE TEST DATE DEC. 67

DATA TO BE USED FOR MATERIAL EVAL.
DO NOT USE FOR DESIGN

FIGURE 4-19 STRESS-STRAIN CURVES FOR AL 7039-T64, WELDED AND TREATED TO T61, AT 140 R. IRRADIATED IN LN

NPC 26,793



CURVE SYMBOL	SPECIMEN NUMBER	STRAIN MEAS. DEVICE	MINIMUM X-SECT. AREA (IN.^{2})	GAGE LENGTH (IN.) NOMINAL	GAGE LENGTH (IN.) EFFECT.	FLUENCE (NEUTRONS/CM^2) THERMAL	FLUENCE (NEUTRONS/CM^2) FAST	GAMMA DOSE (ERGS/GM(C))
X	BW04	INSTRON	0.0317		1.50	2.4+16	1.1+17	1.3+11

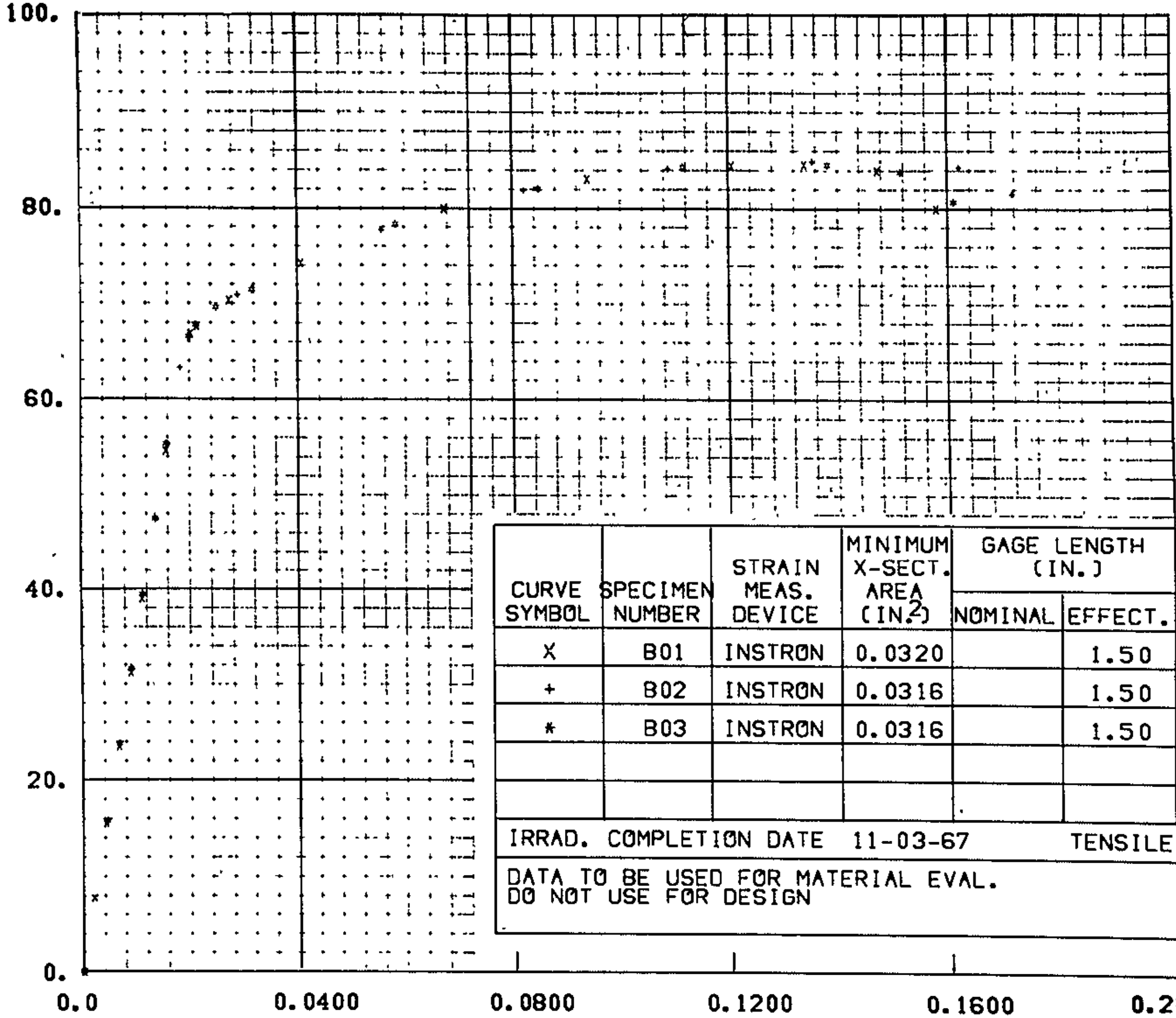
IRRAD. COMPLETION DATE 11-03-67 TENSILE TEST DATE DEC. 67

DATA TO BE USED FOR MATERIAL EVAL.
DO NOT USE FOR DESIGN

STRAIN(IN./IN. OF GAGE LENGTH)(BASED ON HANDBOOK MODULUS)

FIGURE 4-20 STRESS-STRAIN CURVE FOR AL 7039-T64.WELDED AND TREATED TO T61. FITTED TO HANDBOOK MODULUS. IRRAD IN LN

NPC 26,794



CURVE SYMBOL	SPECIMEN NUMBER	STRAIN MEAS. DEVICE	MINIMUM X-SECT. AREA (IN.^{2})	GAGE LENGTH (IN.) NOMINAL	GAGE LENGTH (IN.) EFFECT.	FLUENCE (NEUTRONS/CM^2) THERMAL	FLUENCE (NEUTRONS/CM^2) FAST	GAMMA DOSE (ERGS/ GM(C))
X	B01	INSTRON	0.0320		1.50	CONT		
+	B02	INSTRON	0.0316		1.50	CONT		
*	B03	INSTRON	0.0316		1.50	CONT		

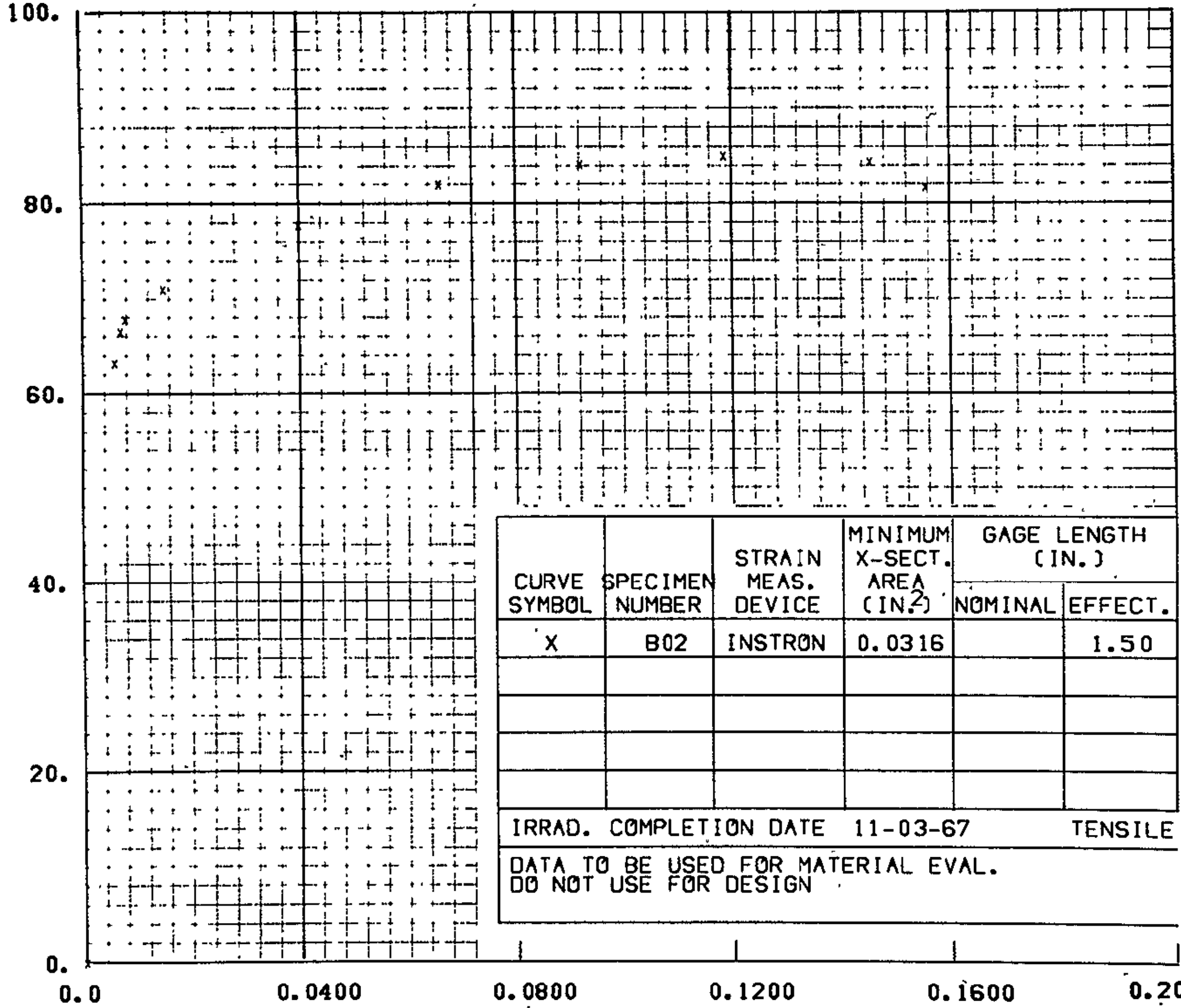
IRRAD. COMPLETION DATE 11-03-67 TENSILE TEST DATE DEC. 67

DATA TO BE USED FOR MATERIAL EVAL.
DO NOT USE FOR DESIGN

STRAIN (IN./IN. OF GAGE LENGTH)(BASED ON CROSSHEAD TRAVEL)

FIGURE 4-21 STRESS-STRAIN CURVES FOR AL 7039-T64 PARENT
AT 140 R. CONTROLS

NPC 26,195



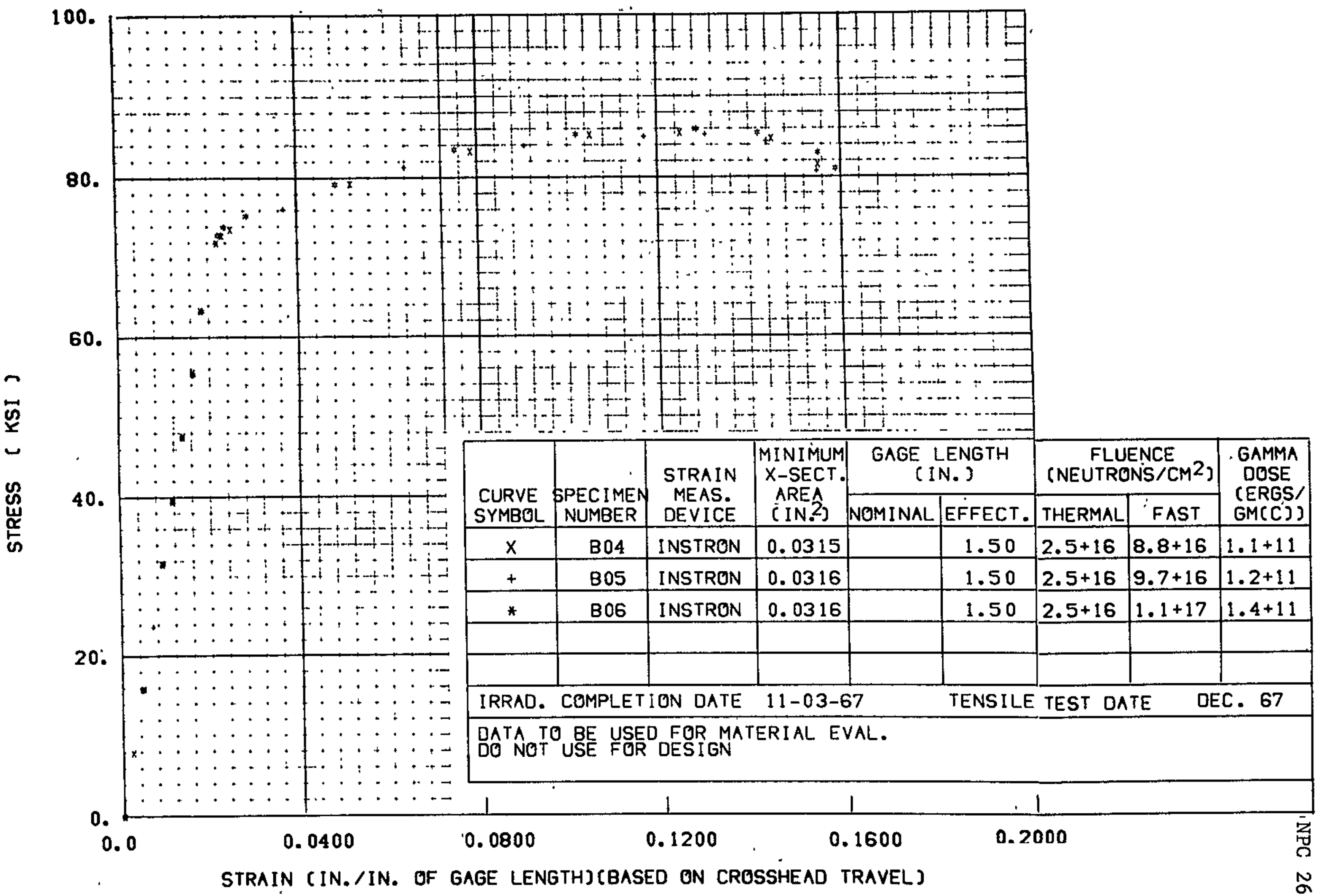
CURVE SYMBOL	SPECIMEN NUMBER	STRAIN MEAS. DEVICE	MINIMUM X-SECT. AREA (IN.^{2})	GAGE LENGTH (IN.) NOMINAL	GAGE LENGTH (IN.) EFFECT.	FLUENCE (NEUTRONS/CM^2) THERMAL	FLUENCE (NEUTRONS/CM^2) FAST	GAMMA DOSE (ERGS/GM(C))
X	B02	INSTRON	0.0316		1.50	CONT		

IRRAD. COMPLETION DATE 11-03-67 TENSILE TEST DATE DEC. 67

DATA TO BE USED FOR MATERIAL EVAL.
DO NOT USE FOR DESIGN

FIGURE 4-22 STRESS-STRAIN CURVE FOR AL 7039-T64 PARENT FITTED TO HANDBOOK MODULUS. CONTROL

NPC 26,796



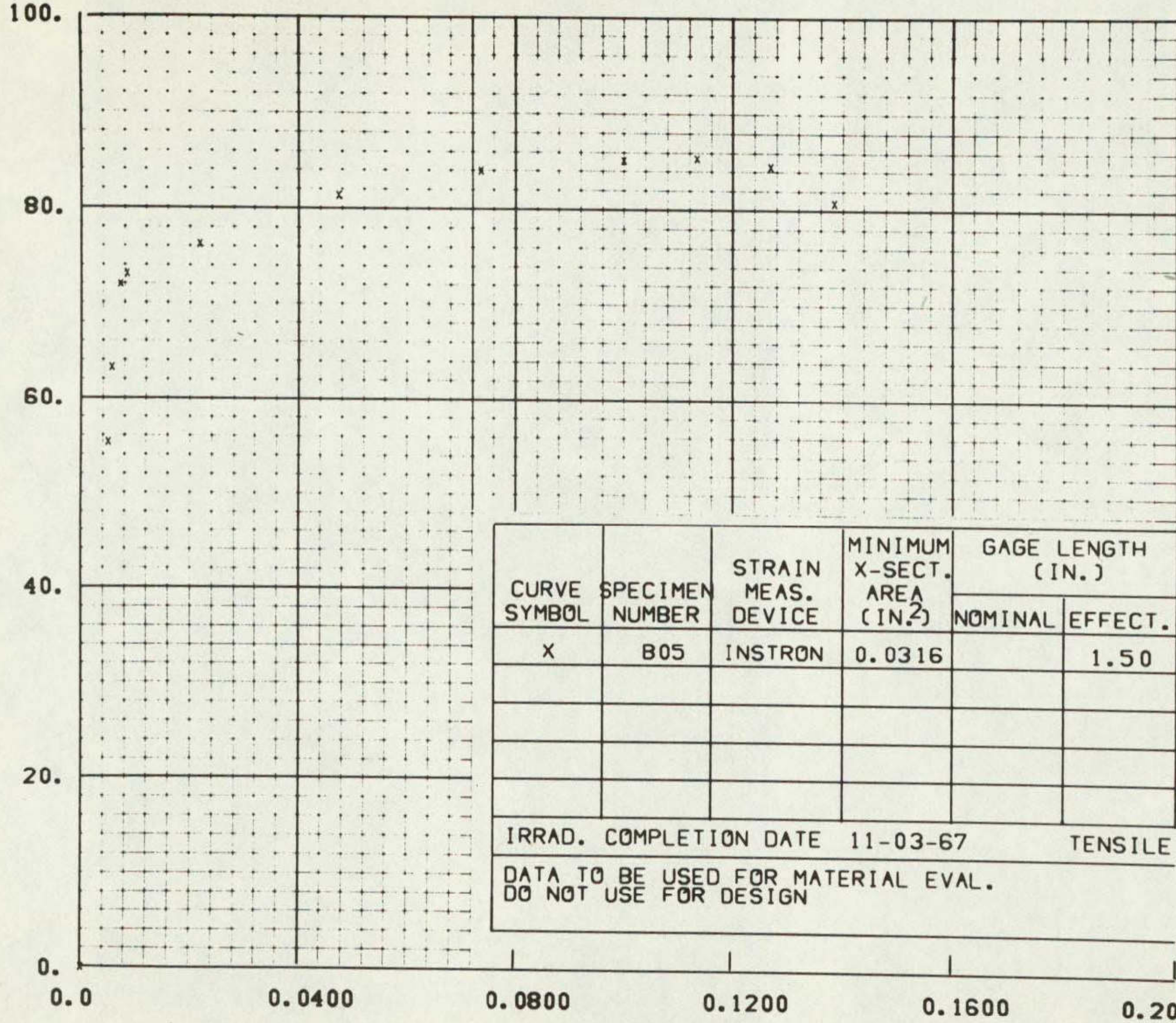
CURVE SYMBOL	SPECIMEN NUMBER	STRAIN MEAS. DEVICE	MINIMUM X-SECT. AREA (IN.^{2})	GAGE LENGTH (IN.) NOMINAL	GAGE LENGTH (IN.) EFFECT.	FLUENCE (NEUTRONS/CM^2) THERMAL	FLUENCE (NEUTRONS/CM^2) FAST	GAMMA DOSE (ERGS/GM(C))
X	B04	INSTRON	0.0315		1.50	2.5+16	8.8+16	1.1+11
+	B05	INSTRON	0.0316		1.50	2.5+16	9.7+16	1.2+11
*	B06	INSTRON	0.0316		1.50	2.5+16	1.1+17	1.4+11

IRRAD. COMPLETION DATE 11-03-67 TENSILE TEST DATE DEC. 67

DATA TO BE USED FOR MATERIAL EVAL.
DO NOT USE FOR DESIGN

FIGURE 4-23 STRESS-STRAIN CURVES FOR AL 7039-T64 PARENT
AT 140 R. IRRADIATED IN LN

NPC 26,797



CURVE SYMBOL	SPECIMEN NUMBER	STRAIN MEAS. DEVICE	MINIMUM X-SECT. AREA (IN.^{2})	GAGE LENGTH (IN.) NOMINAL	EFFECT.	FLUENCE (NEUTRONS/CM^2) THERMAL	FAST	GAMMA DOSE (ERGS/GM(C))
X	B05	INSTRON	0.0316		1.50	2.5+16	9.7+16	1.2+11

IRRAD. COMPLETION DATE 11-03-67 TENSILE TEST DATE DEC. 67

DATA TO BE USED FOR MATERIAL EVAL.
DO NOT USE FOR DESIGN

STRAIN(IN./IN. OF GAGE LENGTH)(BASED ON HANDBOOK MODULUS)

FIGURE 4-24 STRESS-STRAIN CURVE FOR AL 7039-T64 PARENT FITTED TO HANDBOOK MODULUS. IRRADIATED IN LN

NPC 26,798

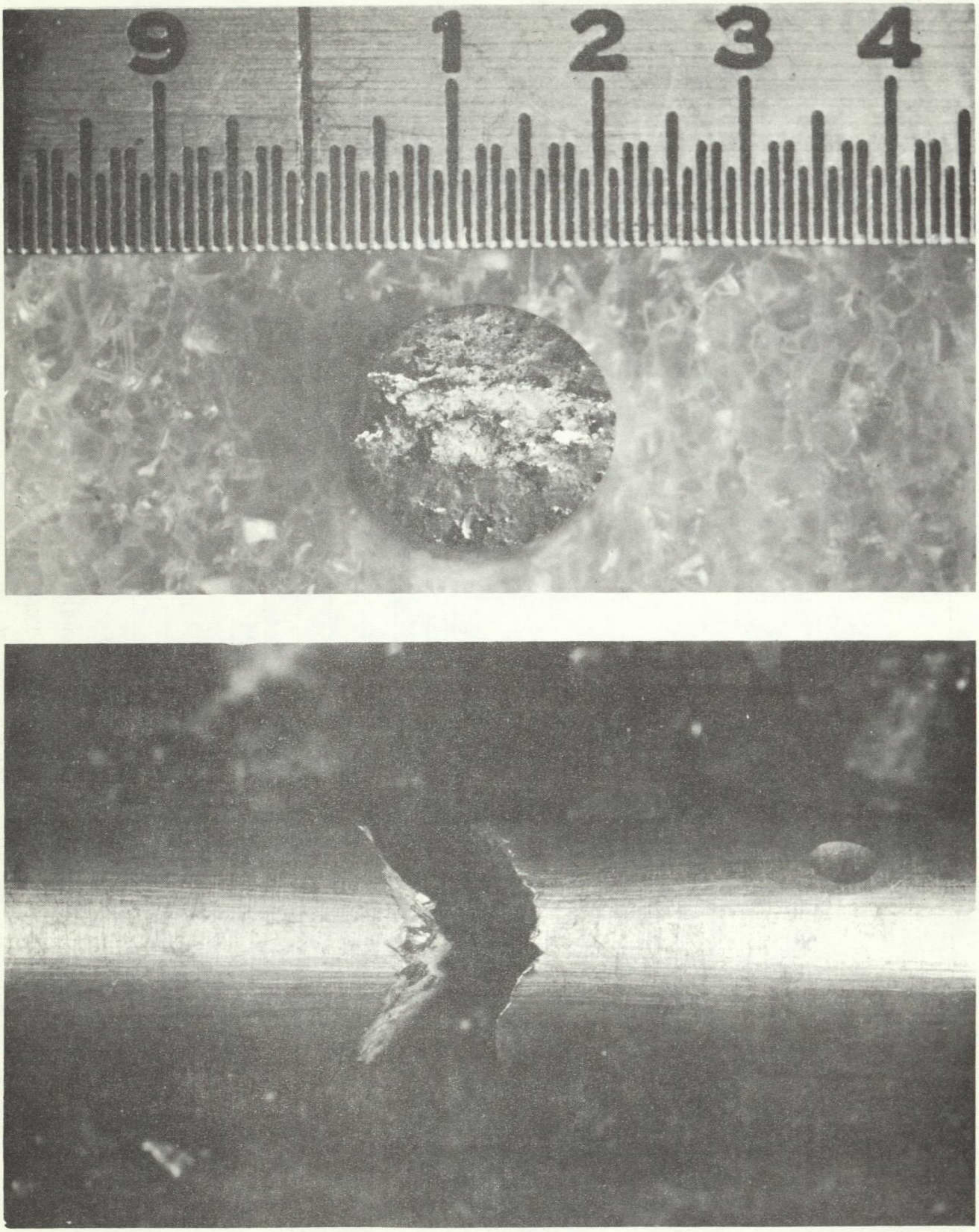


Figure 4-25 Macrograph (10X) of Aluminum 7039-T61 Parent, Specimen A-03: Control

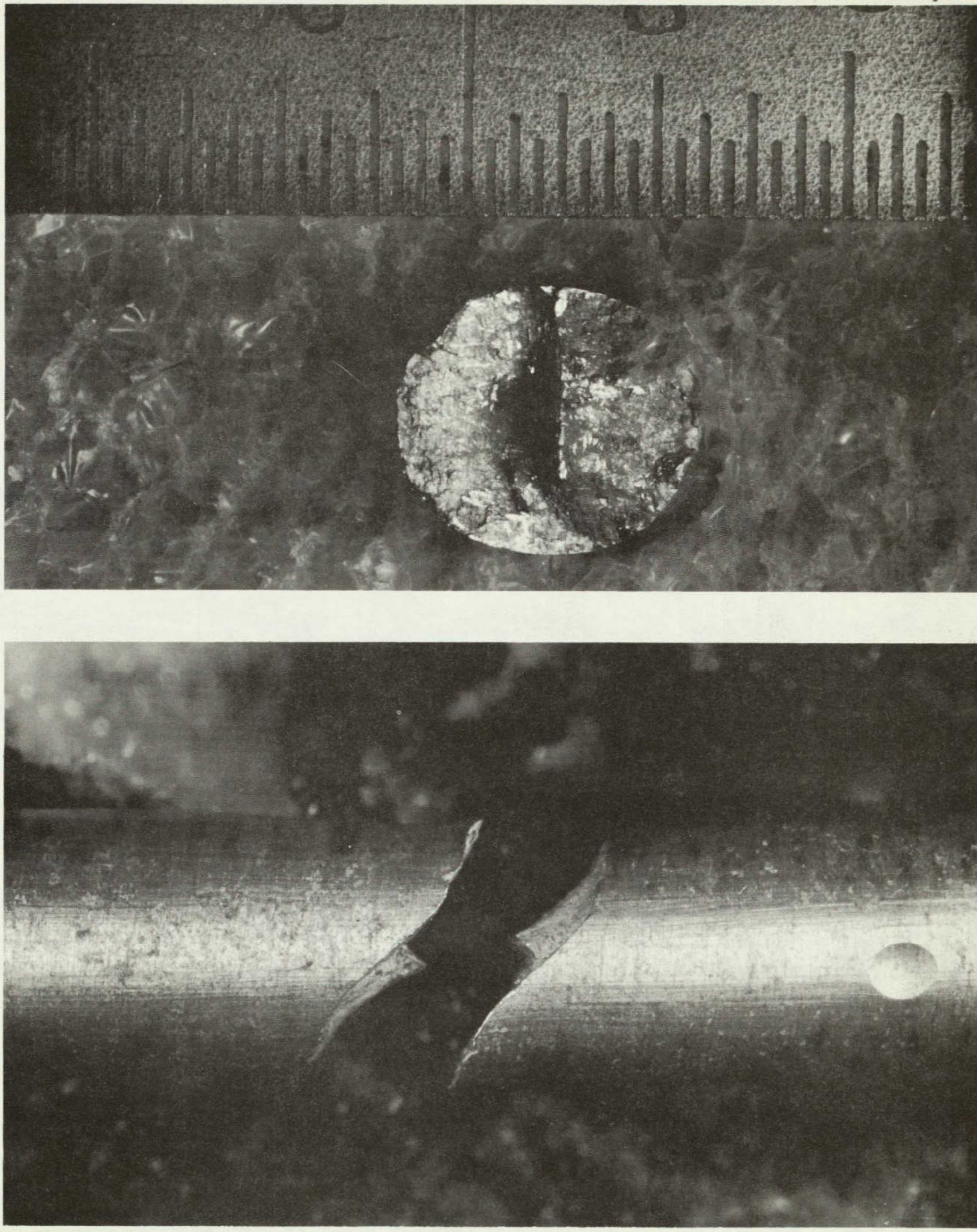


Figure 4-26 Macrograph (10X) of Aluminum 7039-T61 Parent, Specimen A-05: Irradiated at 140°R

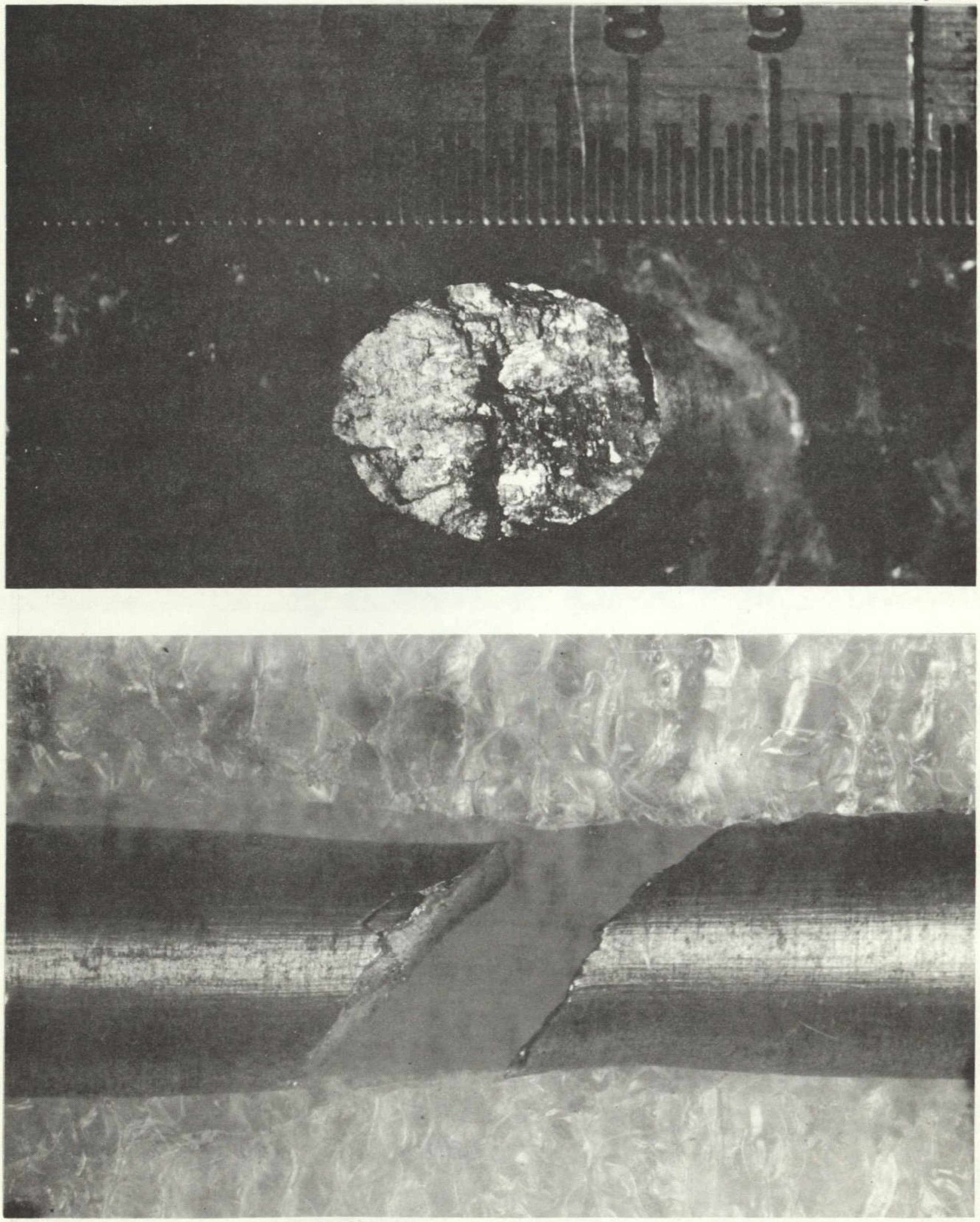


Figure 4-27 Macrograph (10X) of Aluminum 7039-T61 Parent, Specimen A-07: Irradiated at 140°R and Annealed at 440°R

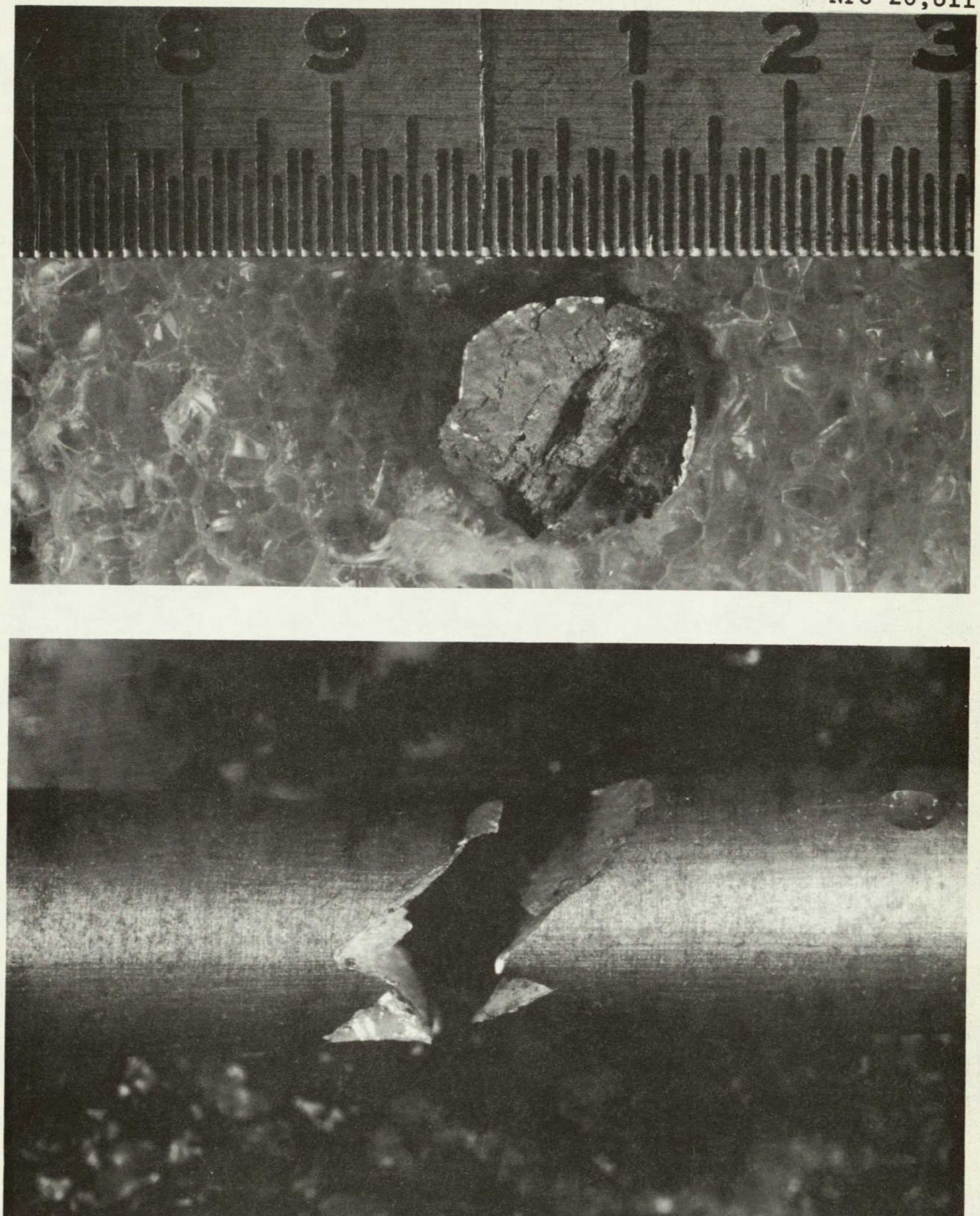


Figure 4-28 Macrograph (10X) of Aluminum 7039-T61 Parent, Specimen A-10: Irradiated at 140°R and Annealed at 540°R

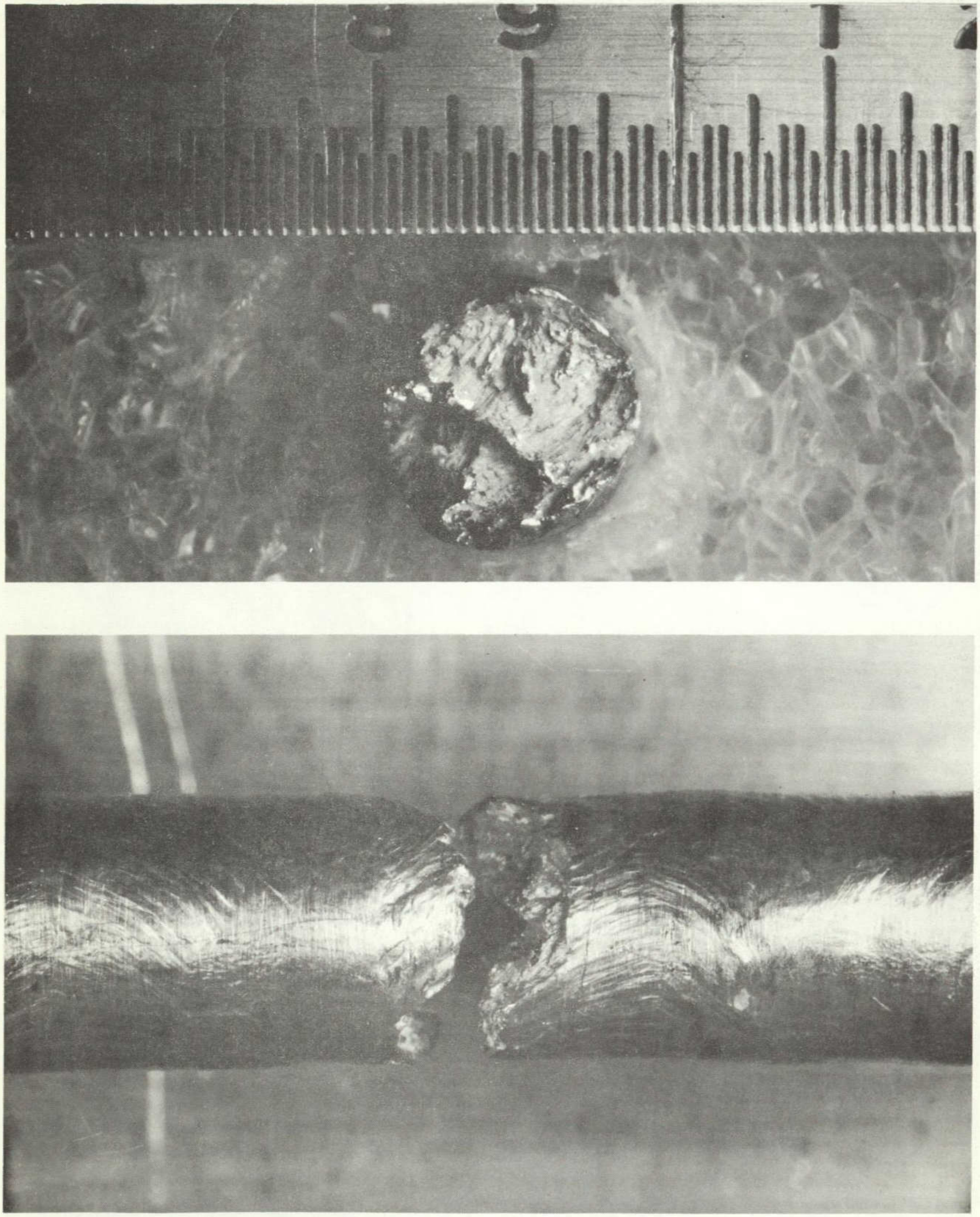


Figure 4-29 Macrograph (10X) of As-Welded Aluminum 7039-T61, Specimen AW-03: Control

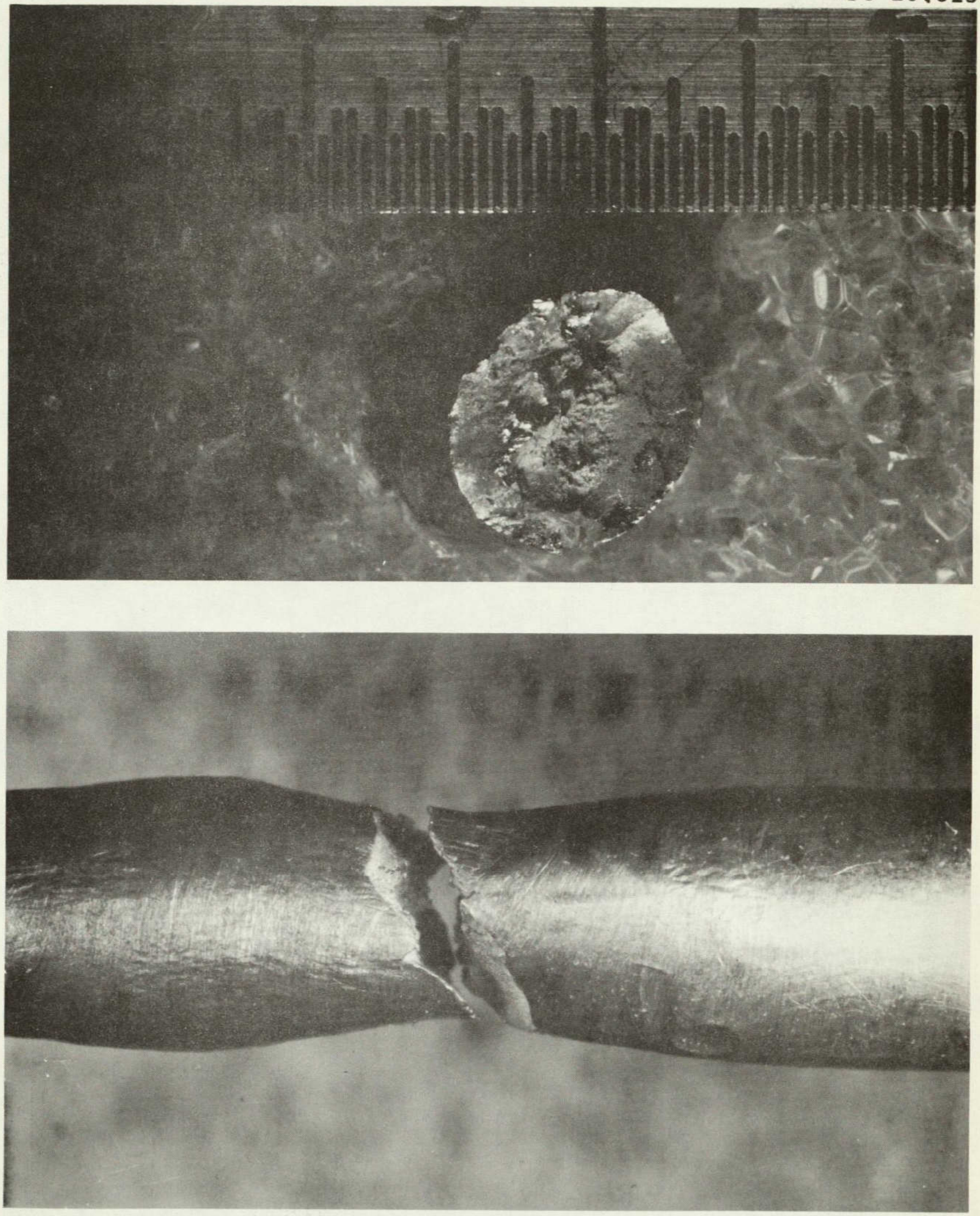


Figure 4-30 Macrograph (10X) of As-Welded Aluminum 7039-T61, Specimen AW-05: Irradiated at 140°R

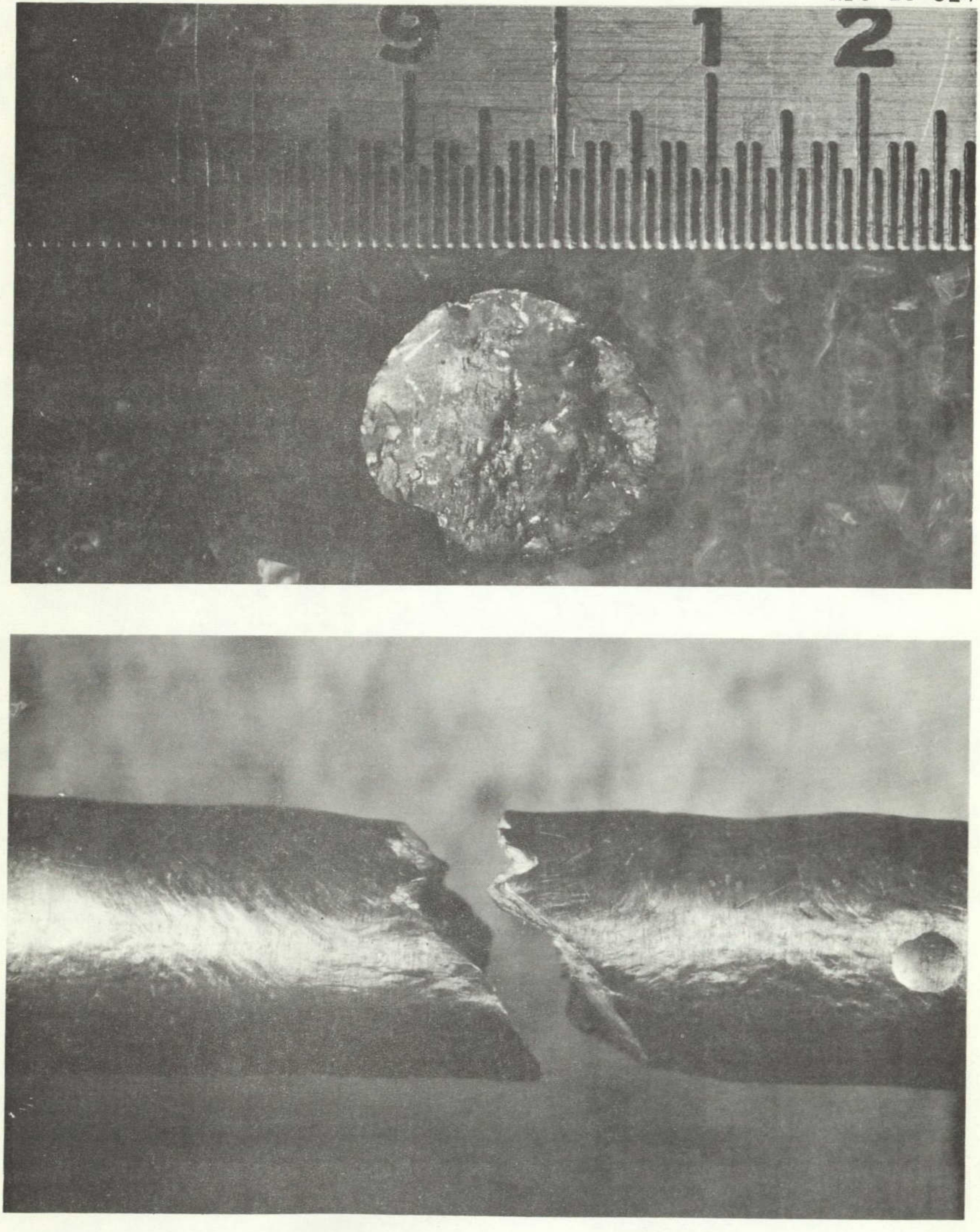


Figure 4-31 Macrograph (10X) of As-Welded Aluminum 7039-T61, Specimen AW-08: Irradiated at 140°R and Annealed at 440°R

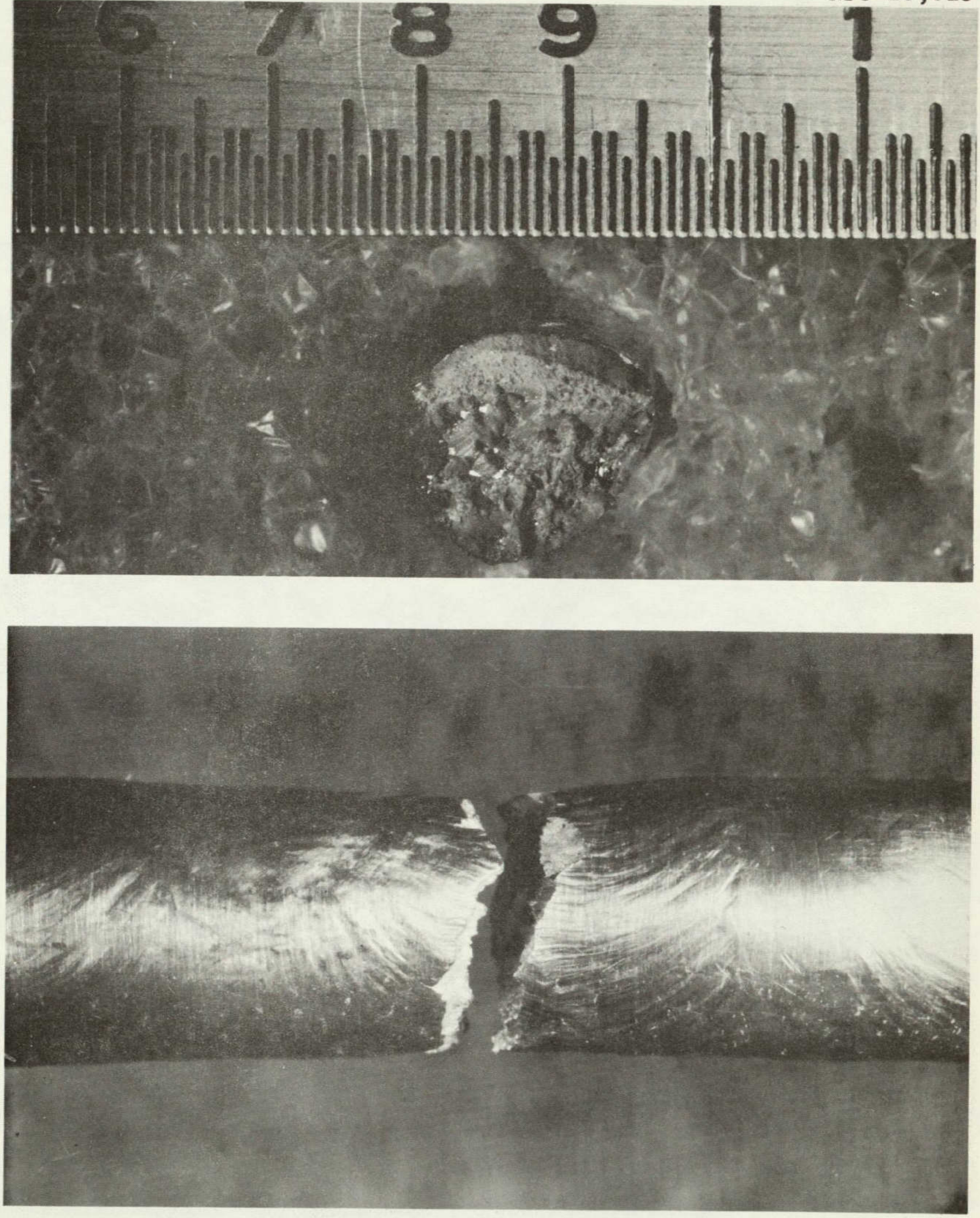


Figure 4-32 Macrograph (10X) of As-Welded Aluminum 7039-T61, Specimen AW-12: Irradiated at 140^{o}R and Annealed at 540^{o}R

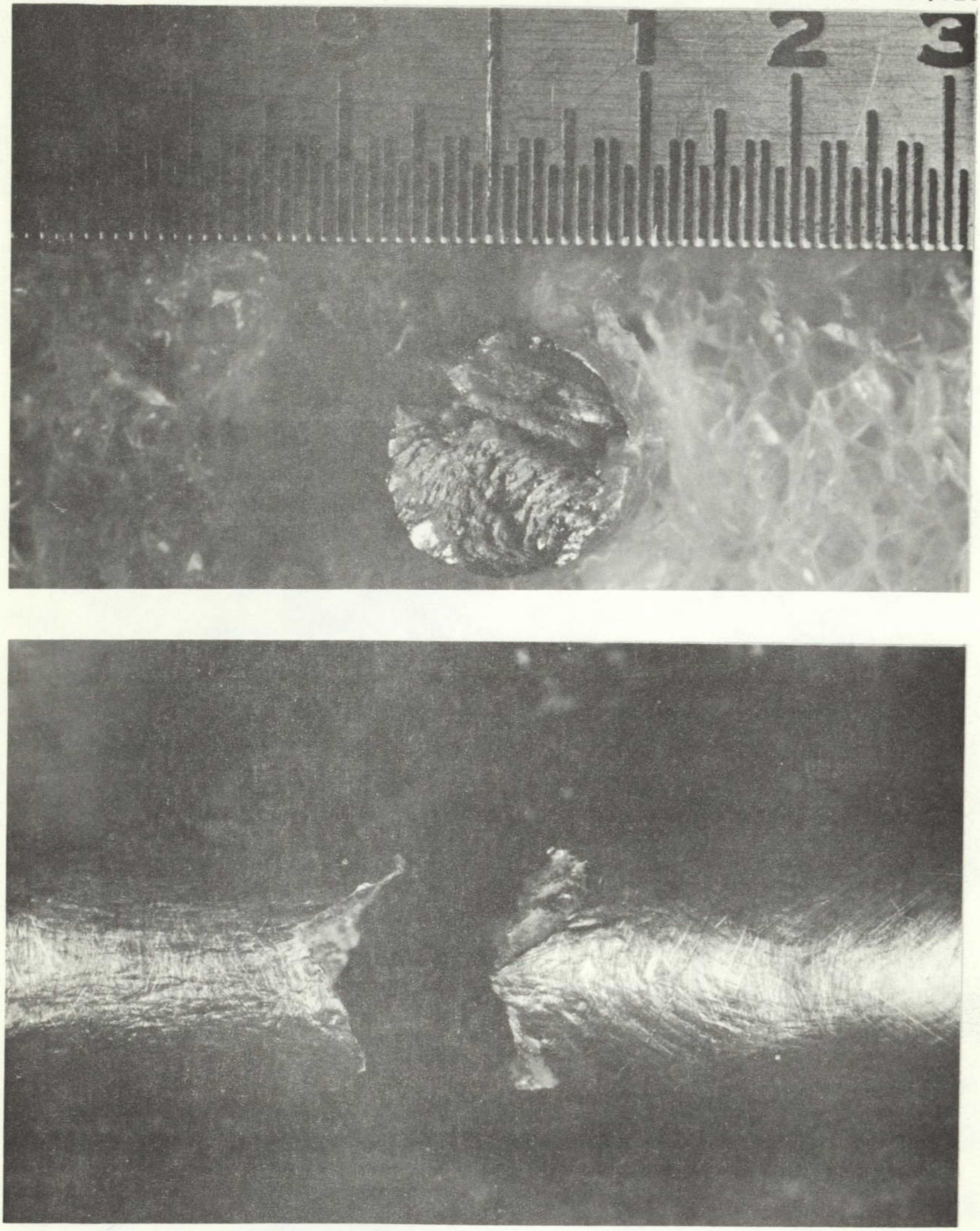


Figure 4-33 Macrograph (10X) of Aluminum 7039-T64 Welded and Treated to T61, Specimen BW-03: Control

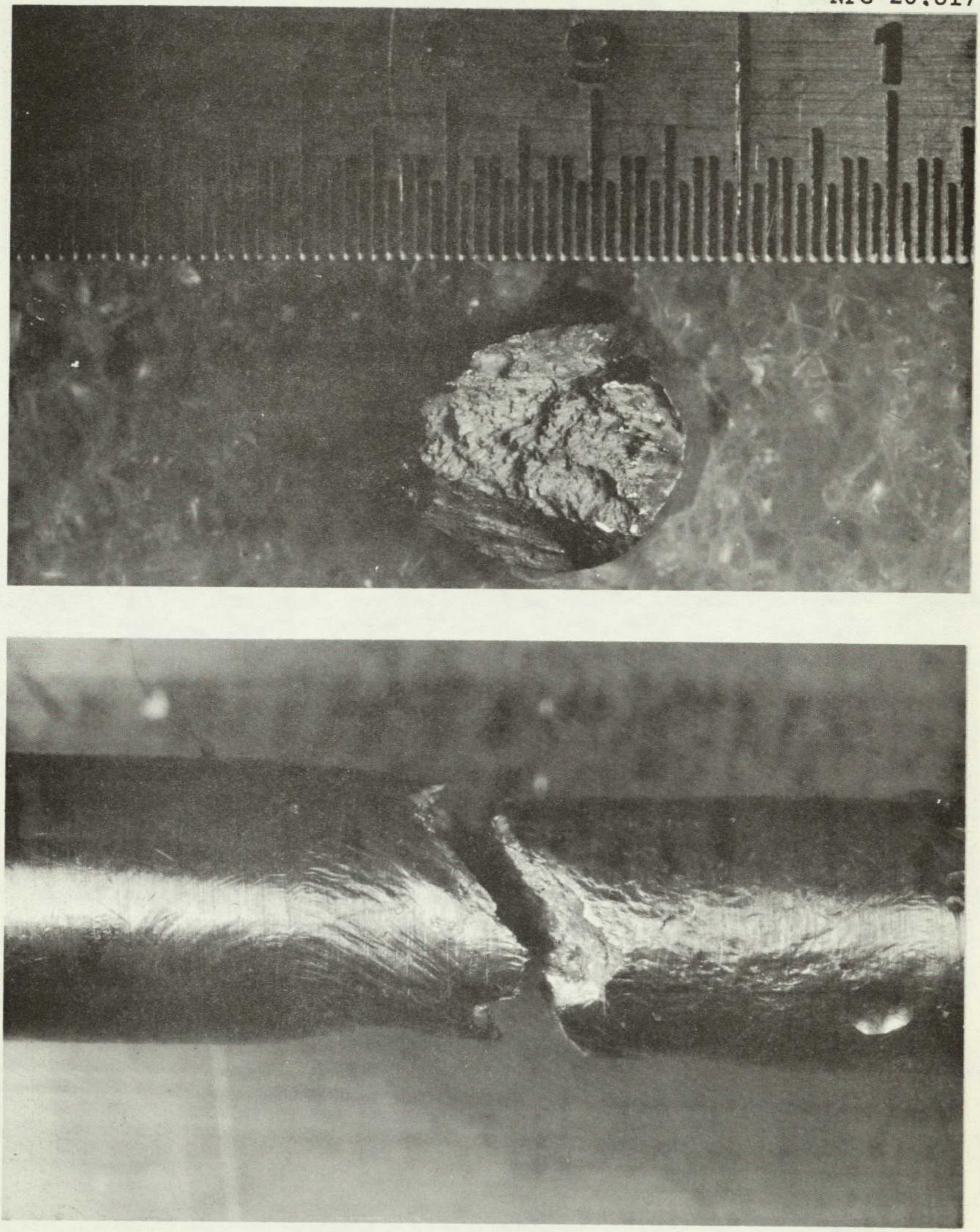


Figure 4-34 Macrograph (10X) of Aluminum 7039-T64 Welded and Treated to T61, Specimen BW-04: Irradiated at $140^{\circ}R$

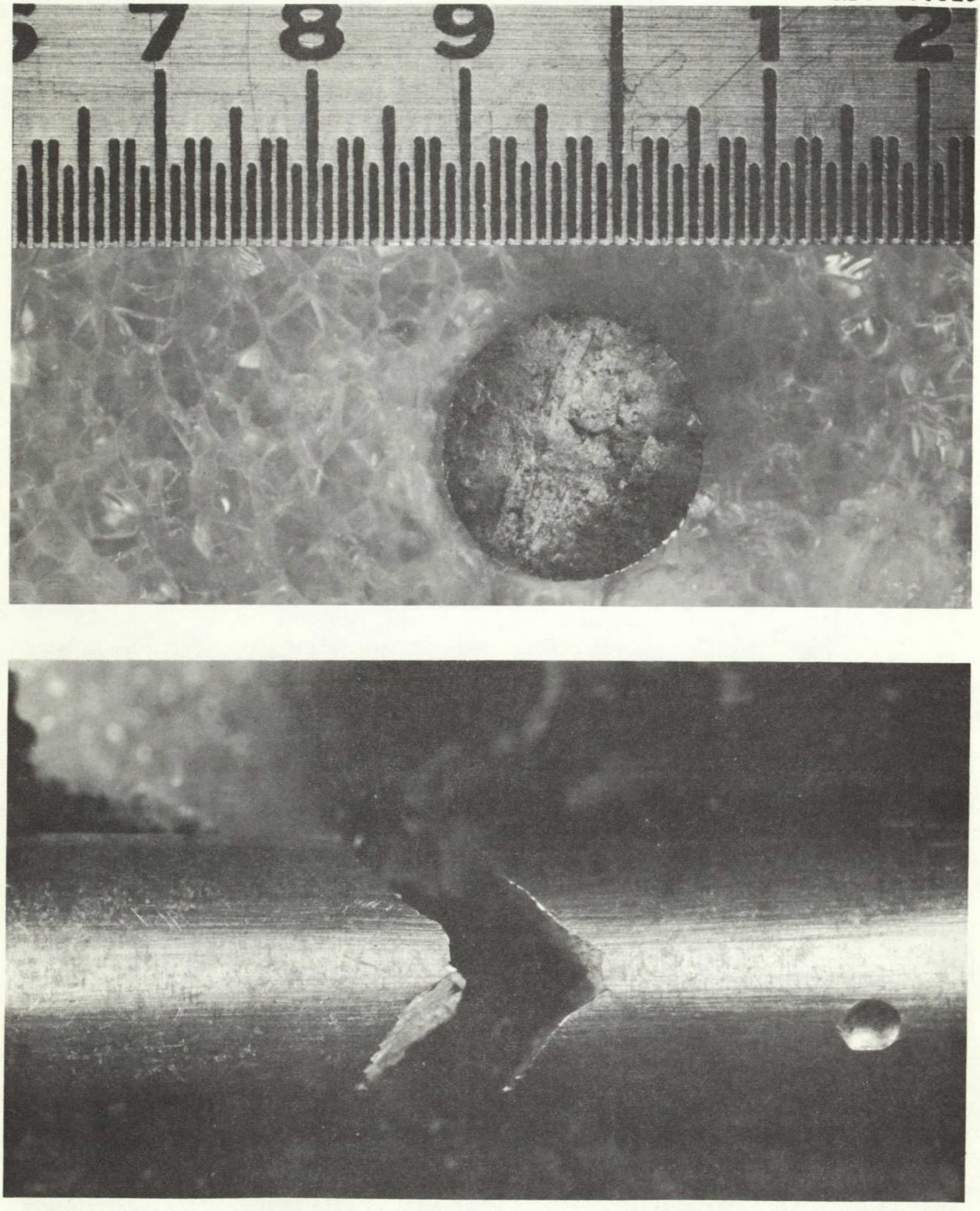


Figure 4-35 Macrograph (10X) of Aluminum 7039-T64, Specimen B-01: Control

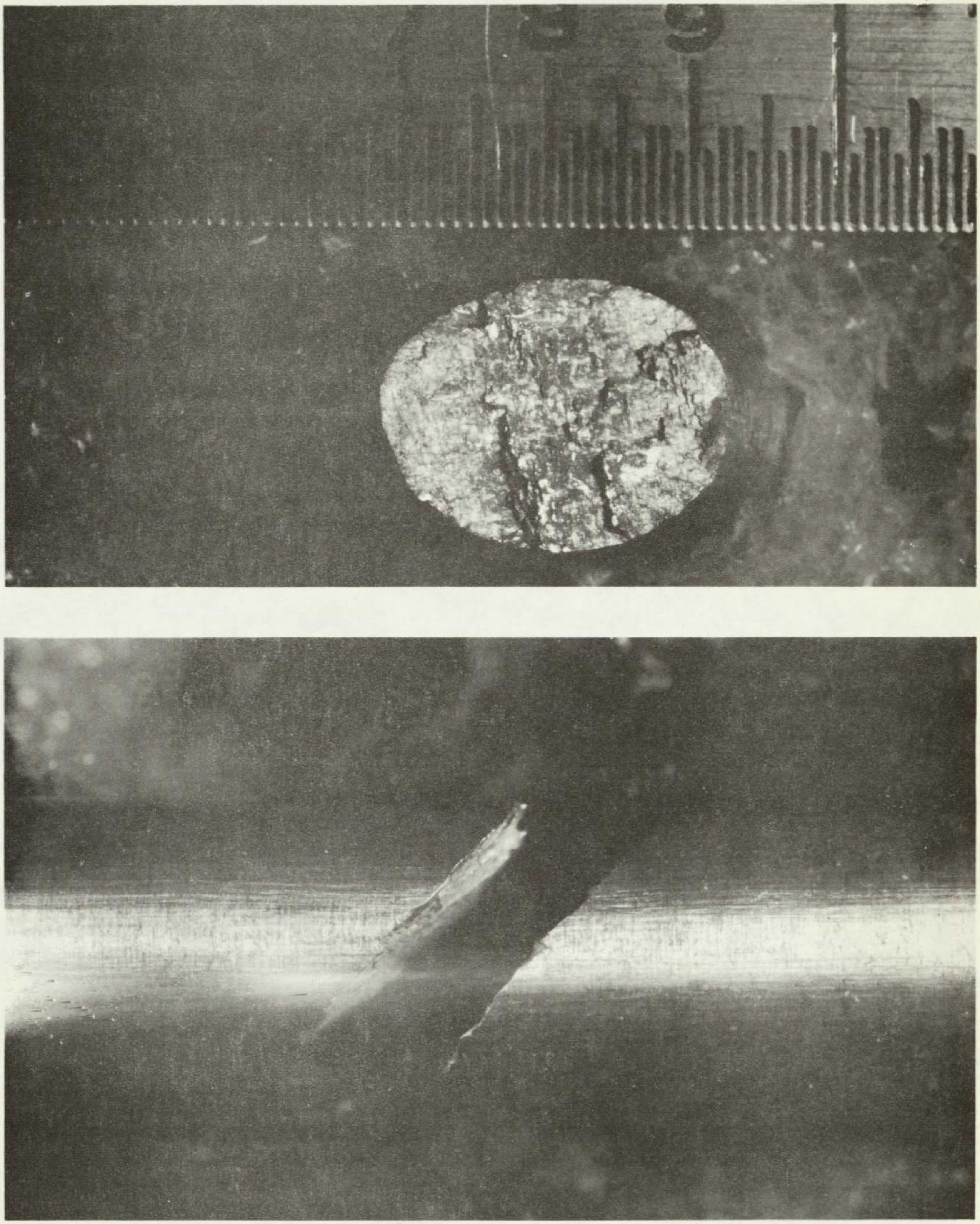


Figure 4-36 Macrograph (10X) of Aluminum 7039-T64, Specimen B-05: Irradiated at 140°R

Section 4.3

Presentation of Hastelloy X Tensile Data

PRECEDING PAGE BLANK NOT FILMED

INDEX TO HASTELLOY TENSILE DATA

Configuration & Material	Condition	Spec. No.	Instron Table	Instron Page	Statistical Comparisons Table	Statistical Comparisons Page
Round-Unnotched Parent	Contr	H 01	4-9	4-70	4-11	4-74
		H 02		4-71		
		H 03				
		H 04				
	Irrad	H 05				
		H 06				
		H 07				
		H 08				
Weldment	Contr	HW 01	4-10	4-72		
		HW 02		4-73		
		HW 03				
		HW 04				
	Irrad	HW 05				
		HW 06				
		HW 07				
		HW 08				

Configuration & Material	Condition	Spec. No.	Stress-Strain Curves Measured Fig.	Measured Page	Fitted Fig.	Fitted Page	Macrography Fig.	Macrography Page
Round-Unnotched Parent	Contr	H 01	4-37	4-76	4-38	4-77	4-45	4-84
		H 02			-	-	-	-
		H 03			-	-	-	-
		H 04			-	-	-	-
	Irrad	H 05	4-39	4-78	-	-	-	-
		H 06			-	-	4-46	4-85
		H 07			4-40	4-79	-	-
		H 08			-	-	-	-
Weldment	Contr	HW 01	4-41	4-80	-	-	-	-
		HW 02			-	-	-	-
		HW 03			-	-	-	-
		HW 04			4-42	4-81	4-47	4-86
	Irrad	HW 05	4-43	4-82	-	-	-	-
		HW 06			4-44	4-83	-	-
		HW 07			-	-	4-48	4-87
		HW 08			-	-	-	-

Table 4-9

TENSILE TEST DATA FOR INDIVIDUAL ROUND-UNNOTCHED SPECIMENS OF HASTELLOY X PARENT

Specimen configuration: round-unnotched - Dwg. No. AGC 1134298-1. Data to be used for material evaluation only. Do not use for design.

Specimen Number	Condition	0.2% Offset Yield Stress (ksi)	Strain @ 0.2% Yield Point (in./in.)	Max Stress (ksi)	Plastic Strain @ Max Stress (in./in.)	Frac Stress (ksi)	Plastic Strain @ Frac Stress (in./in.)	% Elongation Bench	% Elongation Chart	% Area Reduct (Bench)	Frac Location	Radiation Exposure: Gamma Dose [10^{11} ergs/g(C)]	Neutron Fluence (10^{16} n/cm^2) Fast E > 1 MeV	Neutron Fluence (10^{16} n/cm^2) Thermal E < 0.48 eV
H 01	Control	67.0	0.0157	130.1	0.2435	130.1	0.2435	24.1	24.4	21.9	1			
H 02		67.8	0.0168	123.6	0.2158	123.6	0.2158	21.3	21.6	21.1	4			
H 03		66.9	0.0160	123.5	0.2214	123.5	0.2214	22.5	22.1	21.2	1			
H 04		67.7	0.0160	120.0	0.1885	120.0	0.1885	18.5	18.8	26.6	1			
Average		67.4	0.016	124.3	0.217	124.3	0.217	21.6	21.7	22.7				
Std Dev		0.47	0.0005	4.21	0.023	4.21	0.023	2.36	2.3	2.62				
% Std Dev		0.69	2.91	3.39	10.4	3.39	10.4	10.9	10.6	11.5				
H 05	Irrad	86.3	0.0181	125.9	0.1774	125.9	0.1774	17.6	17.7	19.1	1	1.1	8.5	1.8
H 06		88.9	0.0196	127.1	0.1712	127.1	0.1712	17.0	17.1	22.6	1	1.3	10.2	1.8
H 07		91.3	0.0197	132.1	0.1726	132.1	0.1726	16.9	17.3	19.0	2	1.5	12.1	1.8
H 08		92.3	0.0197	129.3	0.1524	129.3	0.1524	15.4	15.2	21.5	1	1.8	14.3	1.8
Average		89.7	0.019	128.6	0.168	128.6	0.168	16.7	16.8	20.6				
Std Dev		2.68	0.0008	2.73	0.011	2.73	0.011	0.94	1.11	1.79				
% Std Dev		2.99	4.05	2.12	6.53	2.12	6.53	5.60	6.61	8.71				

Strain values are based on Instron crosshead travel - not extensometer measurements.
Instron crosshead speed = 0.02 in./min = average strain rate in plastic region of 0.013 in./in./min (based on 1.5-in. gage length
Irradiation Completion Date: 3 November 1967
Irradiation and tensile test temperature: 140°R

Table 4-9 (Cont'd)

Specimen Number	Condition	Plastic & Elastic Strain @ Max Stress (in./in.)	Total Permanent Strain (in./in.)	Plastic & Elastic Strain @ Frac Stress (in./in.)	Modulus of Elasticity[a] (10^6 psi)	Resiliency (in.-lb/in.^{3})	Plasticity (in.-lb/in.^{3})	Energy Absorption (in.-lb/in.^{3})	Hardness, Rockwell B Scale		Test Date (Dec 67)
									As Received	After Testing	
H 01	Control	0.2708	0.2435	0.2708	4.8	574	28,861	28,861	89.9	88.5	18
H 02		0.2433	0.2158	0.2433	4.5	614	24,847	24,847	88.0	88.5	
H 03		0.2475	0.2214	0.2475	4.7	588	25,089	25,089	89.3	87.7	
H 04		0.2132	0.1885	0.2132	4.9	603	20,810	20,810	88.2	91.6	
Average		0.244	0.217	0.244	4.7	595	24,902	24,902	88.9	89.1	
Std Dev		0.024	0.023	0.024	0.17	17.4	3,289	3,289	0.90	1.73	
% Sted Dev		9.71	10.4	9.71	3.61	2.94	13.2	13.2	1.02	1.94	
H 05	Irrad	0.2008	0.1773	0.2008	5.4	859	21,517	21,517	87.8	91.4	18
H 06		0.1963	0.1712	0.1963	5.1	950	21,164	21,164	87.2	92.4	
H 07		0.1981	0.1725	0.1981	5.2	983	22,078	22,078	89.1	93.0	
H 08		0.1764	0.1523	0.1764	5.4	951	19,354	19,354	89.4	94.3	
Average		0.193	0.168	0.193	5.3	936	21,028	21,028	88.4	92.8	
Std Dev		0.011	0.011	0.011	0.15	53.4	1,178	1,178	1.05	1.21	
% Std Dev		5.78	6.54	5.78	2.84	5.71	5.60	5.60	1.19	1.31	

[a]Moduli reported are based on uncorrected Instron measurements. Literature value for modulus of elasticity for control specimens of this material at 140°R is 32.0 x 10^6 psi.

Table 4-10

TENSILE TEST DATA FOR INDIVIDUAL ROUND-UNNOTCHED SPECIMENS OF HASTELLOY X WELDMENT

Specimen configuration: round-unnotched - Dwg. No. AGC 1134298-1. Data to be used for material evaluation only. Do not use for design.

Specimen Number	Condition	0.2% Offset Yield Stress (ksi)	Strain @ 0.2% Yield Point (in./in.)	Max Stress (ksi)	Plastic Strain @ Max Stress (in./in.)	Frac Stress (ksi)	Plastic Strain @ Frac Stress (in./in.)	% Elongation		% Area Reduct (Bench)	Frac Location	Radiation Exposure		
								Bench	Chart			Gamma Dose [10^{11} ergs/g(C)]	Neutron Fluence (10^{16} n/cm^2) Fast E >1 MeV	Thermal E < 0.48 eV
HW 01	Control	69.6	0.0163	125.2	0.1564	123.5	0.1573	15.5	15.7	21.2	4			
HW 02		70.4	0.0164	125.7	0.1908	125.4	0.1667	16.4	16.7	20.9	3			
HW 03		70.4	0.0176	124.6	0.1611	124.6	0.1611	15.9	16.1	20.4	4			
HW 04		70.3	0.0168	127.4	0.1768	127.4	0.1768	17.7	17.7	21.9	3			
Average		70.2	0.0168	125.7	0.171	125.2	0.165	16.4	16.6	21.1				
Std Dev		0.39	0.0006	1.20	0.016	1.65	0.008	0.96	0.87	0.63				
% Std Dev		0.55	3.53	0.96	9.15	1.31	5.13	5.84	5.26	2.97				
HW 05	Irrad	88.8	0.0197	129.8	0.1363	129.8	0.1363	13.5	13.6	18.4	3	1.1	8.5	1.7
HW 06		90.3	0.0195	129.3	0.1243	128.3	0.1258	14.1	12.6	19.3	3	1.3	10.1	1.7
HW 07		92.4	0.0201	131.2	0.1244	130.9	0.1353	12.7	13.5	19.2	3	1.5	12.1	1.7
HW 08		94.1	0.0196	129.3	0.1196	129.3	0.1196	12.1	12.0	16.8	3	1.9	15.1	1.7
Average		91.4	0.0197	129.9	0.126	129.6	0.129	13.1	12.9	18.4				
Std Dev		2.33	0.0003	0.90	0.007	1.08	0.008	0.88	0.76	1.16				
% Std Dev		2.55	1.34	0.69	5.65	0.83	6.18	6.71	5.91	6.27				

Strain values are based on Instron crosshead travel - not extensometer measurements.
Instron crosshead speed = 0.02 in./min = average strain rate in plastic region of 0.013 in./in./min (based on 1.5-in. gage length)
Irradiation Completion Date: 3 November 1967
Irradiation and tensile test temperature: $140^{\circ}R$

Table 4-10 (Cont'd)

Specimen Number	Condition	Plastic & Elastic Strain @ Max Stress (in./in.)	Total Permanent Strain (in./in.)	Plastic & Elastic Strain @ Frac Stress (in./in.)	Modulus of Elasticity (10^6 psi)	Resiliency (in.-lb/in.^{3})	Plasticity (in.-lb/in.^{3})	Energy Absorption (in.-lb/in.^{3})	Hardness, Rockwell B Scale		Test Date (Dec 6
									As Received	After Testing	
HW 01	Control	0.1823	0.1573	0.1828	4.8	617	18,234	18,300	87.5	87.8	19
HW 02		0.1908	0.1667	0.1920	5.0	635	19,281	19,432	88.1	86.9	
HW 03		0.1888	0.1611	0.1888	4.5	677	18,854	18,854	87.1	90.2	
HW 04		0.2040	0.1768	0.2040	4.7	646	20,939	20,939	88.2	86.9	
Average		0.191	0.165	0.192	4.75	643	19,327	19,381	87.7	88.0	
Std Dev		0.009	0.008	0.009	0.21	25.2	1,157	1,136	0.52	1.56	
% Std Dev		4.76	5.13	4.65	4.38	3.91	5.99	5.87	0.59	1.77	
HW 05	Irrad	0.1620	0.1363	0.1620	5.1	954	17,406	17,406	87.2	91.9	19
HW 06		0.1493	0.1258	0.1507	5.2	953	15,967	16,139	87.2	91.4	
HW 07		0.1503	0.1353	0.1611	5.1	1005	16,243	17,659	87.4	92.4	
HW 08		0.1440	0.1196	0.1440	5.3	1000	15,568	15,568	87.4	92.4	
Average		0.151	0.129	0.154	5.2	978	16,296	16,693	87.3	92.0	
Std Dev		0.008	0.008	0.009	0.10	28.4	790	1,002	0.12	0.48	
% Std Dev		5.01	6.18	5.60	1.85	2.90	4.85	6.01	0.13	0.52	

[a]Moduli reported are based on uncorrected Instron measurements. Literature value for modulus of elasticity for control specimens of this material at 140°R is 11.0×10^6 psi.

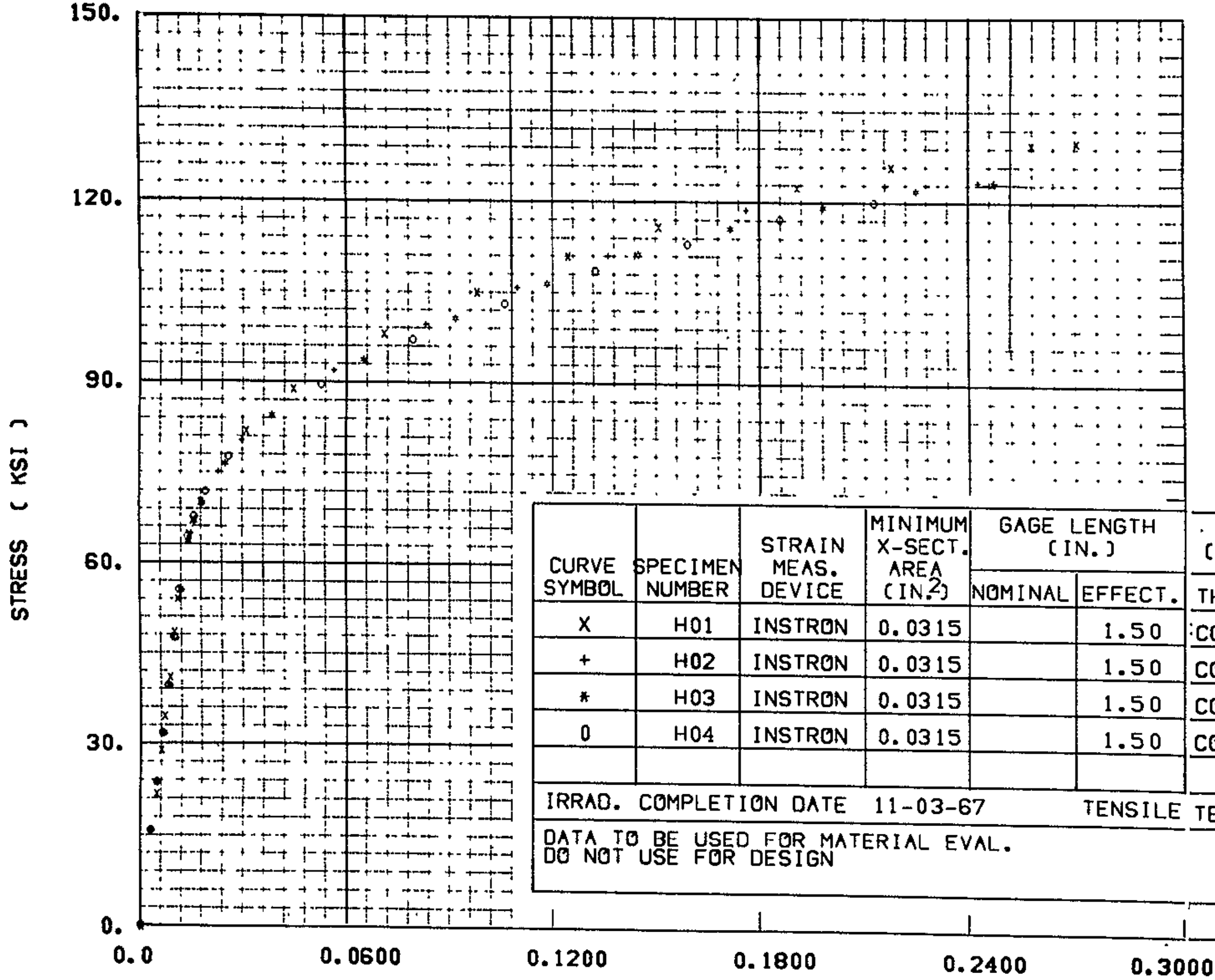
Table 4-11

EFFECT OF TEST CONDITIONS ON THE PROPERTIES OF HASTELLOY X - COMPARISON ON AN ABSOLUTE-VALUE AND PERCENT-CHANGE BASIS

Material	Specimen Data Compared[a]	90% Confidence Interval on Difference Between Averages Compared		
Absolute-Value Basis		0.2% Offset Yield Stress (ksi)	Maximum Stress (ksi)	Fracture Stress (ksi)
		30 (-) 20 10 0 10 (+) 20 30	12 (-) 8 4 0 4 (+) 8 12	6 (-) 4 2 0 2 (+) 4 6
Hastelloy X, parent	Control vs irradiated			
Hastelloy X, weldment	Control vs irradiated			
		% Elongation - Bench	% Elongation - Chart	% Area Reduction
		6 4 2 0 2 4 6	6 4 2 0 2 4 6	6 4 2 0 2 4 6
Hastelloy X, parent	Control vs irradiated			
Hastelloy X, weldment	Control vs irradiated			
Percent-Change Basis		0.2% Offset Yield Stress	Maximum Stress	Fracture Stress
		30 20 10 0 10 20 30	7.5 5 2.5 0 2.5 5 7.5	7.5 5 2.5 0 2.5 5 7.5
Hastelloy X, parent	Control vs irradiated			
Hastelloy X, weldment	Control vs irradiated			
		% Elongation - Bench	% Elongation - Chart	% Area Reduction
		30 20 10 0 10 20 30	30 20 10 0 10 20 30	30 20 10 0 10 20 30
Hastelloy X, parent	Control vs irradiated			
Hastelloy X, weldment	Control vs irradiated			

[a] Comparison is always second condition compared to the first condition.

Stress-Strain Curves



CURVE SYMBOL	SPECIMEN NUMBER	STRAIN MEAS. DEVICE	MINIMUM X-SECT. AREA (IN.^{2})	GAGE LENGTH (IN.) NOMINAL	GAGE LENGTH (IN.) EFFECT.	FLUENCE (NEUTRONS/CM^2) THERMAL	FLUENCE (NEUTRONS/CM^2) FAST	GAMMA DOSE (ERGS/GM(C))
X	H01	INSTRON	0.0315		1.50	CONT		
+	H02	INSTRON	0.0315		1.50	CONT		
*	H03	INSTRON	0.0315		1.50	CONT		
0	H04	INSTRON	0.0315		1.50	CONT		

IRRAD. COMPLETION DATE 11-03-67 TENSILE TEST DATE DEC. 67

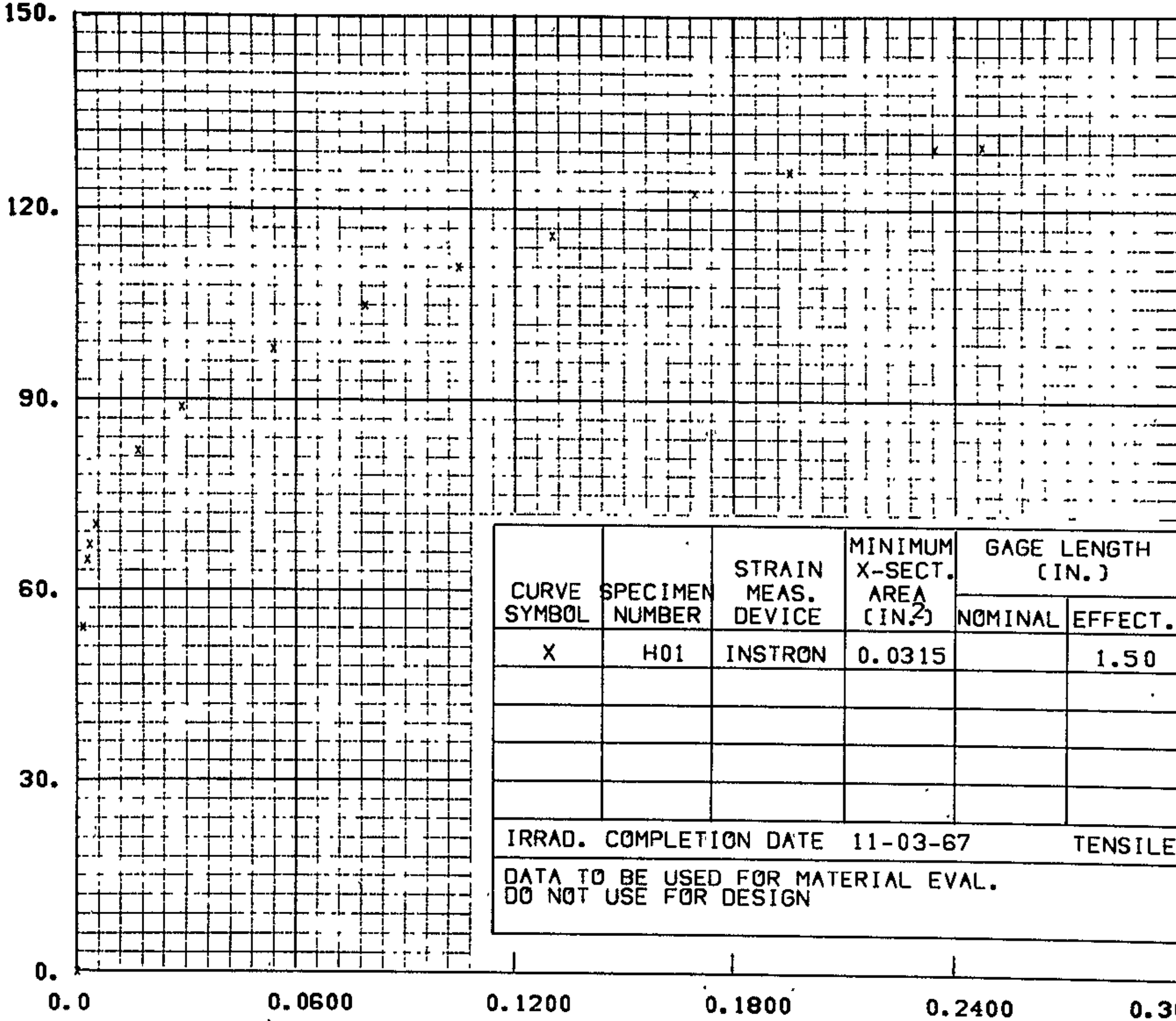
DATA TO BE USED FOR MATERIAL EVAL.
DO NOT USE FOR DESIGN

STRAIN (IN./IN. OF GAGE LENGTH)(BASED ON CROSSHEAD TRAVEL)

FIGURE 4-37 STRESS-STRAIN CURVES FOR HASTELLOY X AT 140 R.
CONTROLS

NOT REPRODUCIBLE

NPC 26,799



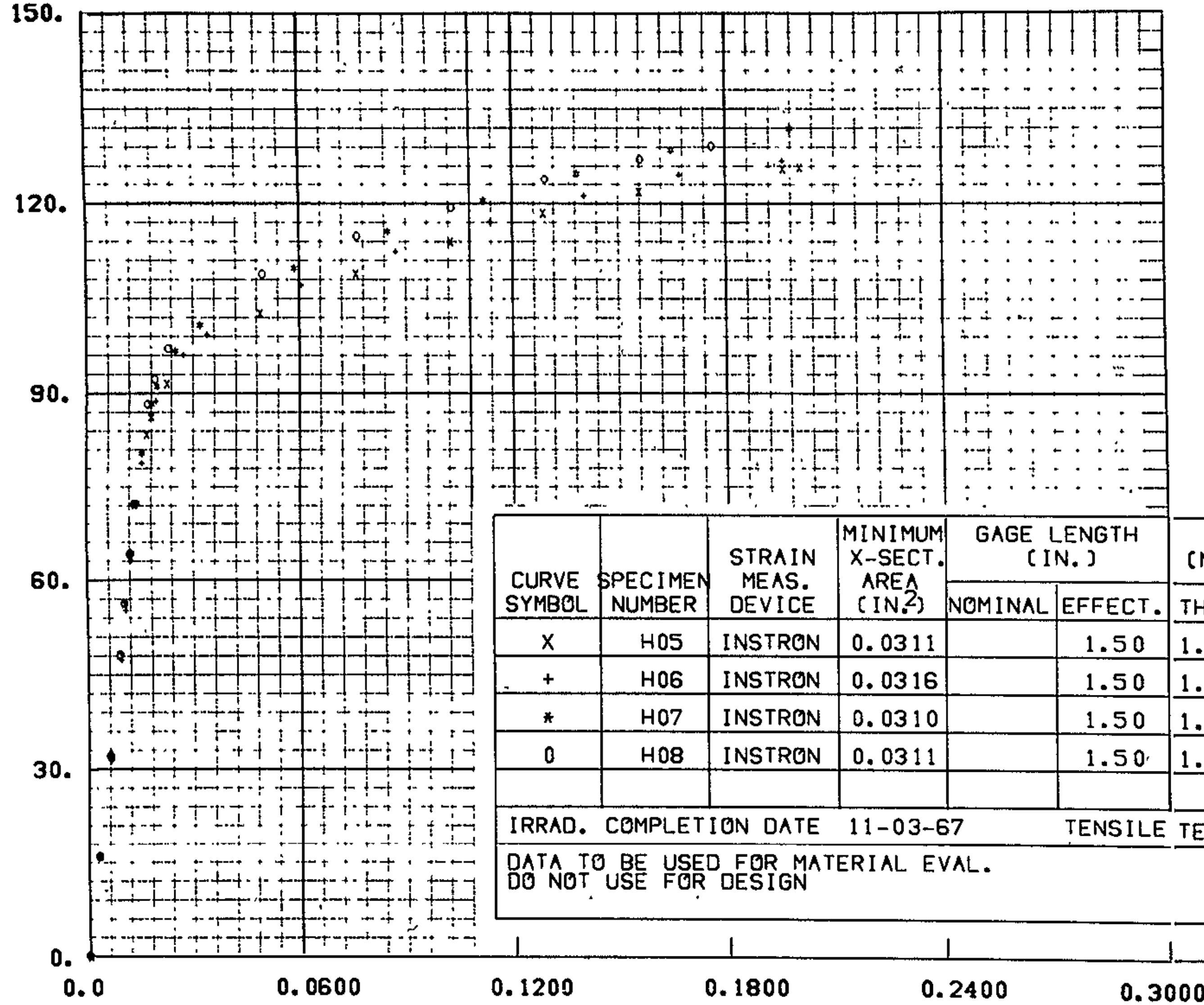
CURVE SYMBOL	SPECIMEN NUMBER	STRAIN MEAS. DEVICE	MINIMUM X-SECT. AREA (IN.^{2})	GAGE LENGTH (IN.) NOMINAL	GAGE LENGTH (IN.) EFFECT.	FLUENCE (NEUTRONS/CM^2) THERMAL	FLUENCE (NEUTRONS/CM^2) FAST	GAMMA DOSE (ERGS/GM(C))
X	H01	INSTRON	0.0315		1.50	CONT		

IRRAD. COMPLETION DATE 11-03-67 TENSILE TEST DATE DEC. 67

DATA TO BE USED FOR MATERIAL EVAL.
DO NOT USE FOR DESIGN

STRAIN(IN./IN. OF GAGE LENGTH)(BASED ON HANDBOOK MODULUS)

FIGURE 4-38 STRESS-STRAIN CURVE FOR HASTELLOY X FITTED TO HANDBOOK MODULUS. CONTROL



CURVE SYMBOL	SPECIMEN NUMBER	STRAIN MEAS. DEVICE	MINIMUM X-SECT. AREA (IN.^{2})	GAGE LENGTH (IN.)		FLUENCE (NEUTRONS/CM^2)		GAMMA DOSE (ERGS/GM(C))
				NOMINAL	EFFECT.	THERMAL	FAST	
X	H05	INSTRON	0.0311		1.50	1.8+16	8.5+16	1.1+11
+	H06	INSTRON	0.0316		1.50	1.8+16	1.0+17	1.3+11
*	H07	INSTRON	0.0310		1.50	1.8+16	1.2+17	1.5+11
O	H08	INSTRON	0.0311		1.50	1.8+16	1.4+17	1.8+11

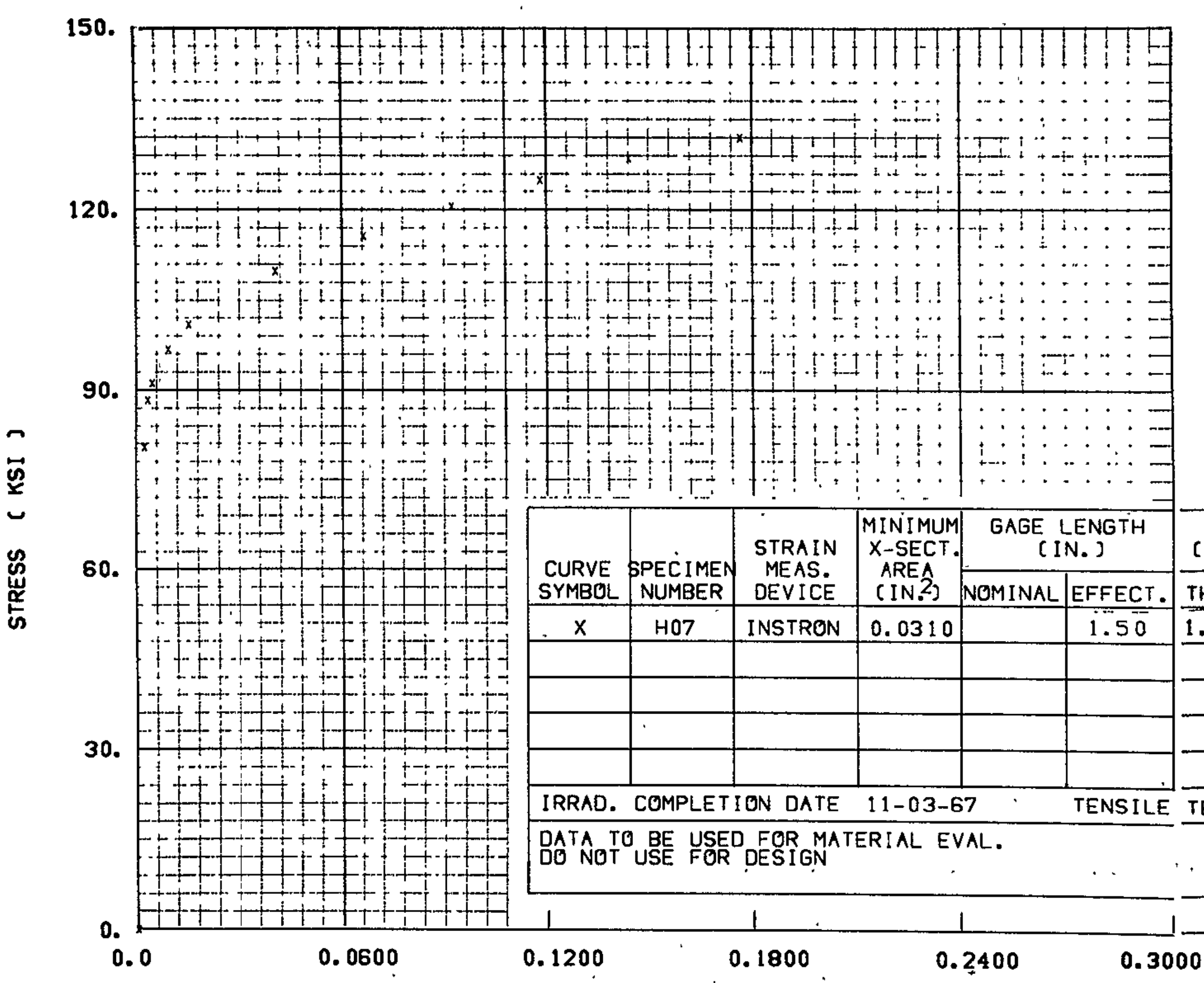
IRRAD. COMPLETION DATE 11-03-67 TENSILE TEST DATE DEC. 67

DATA TO BE USED FOR MATERIAL EVAL.
DO NOT USE FOR DESIGN

STRAIN (IN./IN. OF GAGE LENGTH)(BASED ON CROSSHEAD TRAVEL)

FIGURE 4-39 STRESS-STRAIN CURVES FOR HASTELLOY X AT 140 R. IRRADIATED IN LN.

NPC 26,801



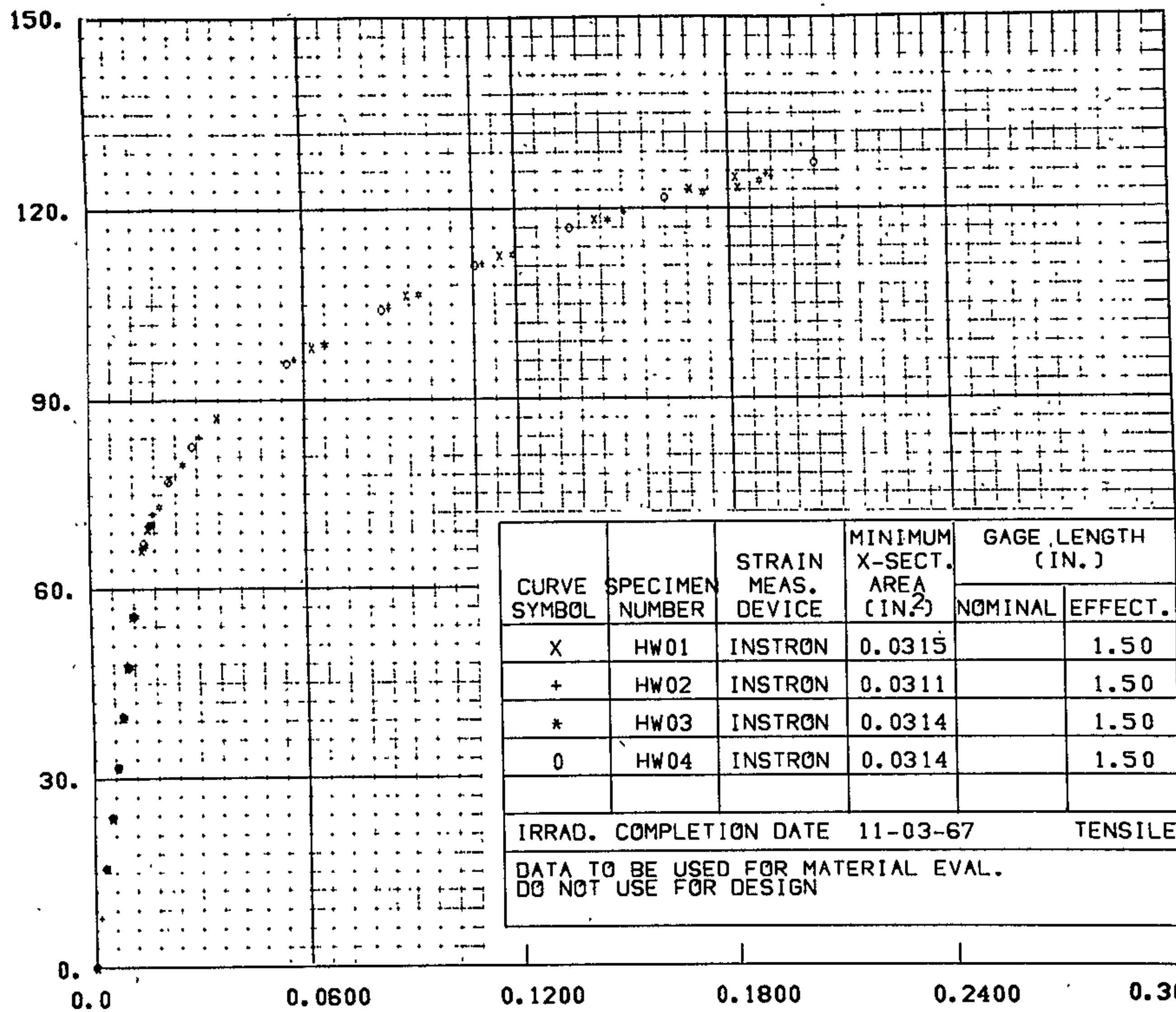
CURVE SYMBOL	SPECIMEN NUMBER	STRAIN MEAS. DEVICE	MINIMUM X-SECT. AREA (IN.^{2})	GAGE LENGTH (IN.) NOMINAL	GAGE LENGTH (IN.) EFFECT.	FLUENCE (NEUTRONS/CM^2) THERMAL	FLUENCE (NEUTRONS/CM^2) FAST	GAMMA DOSE (ERGS/GM(C))
X	H07	INSTRON	0.0310		1.50	1.8+16	1.2+17	1.5+11

IRRAD. COMPLETION DATE 11-03-67 TENSILE TEST DATE DEC. 67

DATA TO BE USED FOR MATERIAL EVAL.
DO NOT USE FOR DESIGN

FIGURE 4-40 STRESS-STRAIN CURVE FOR HASTELLOY X FITTED TO HANDBOOK MODULUS. IRRADIATED IN LN

NPC 26,802



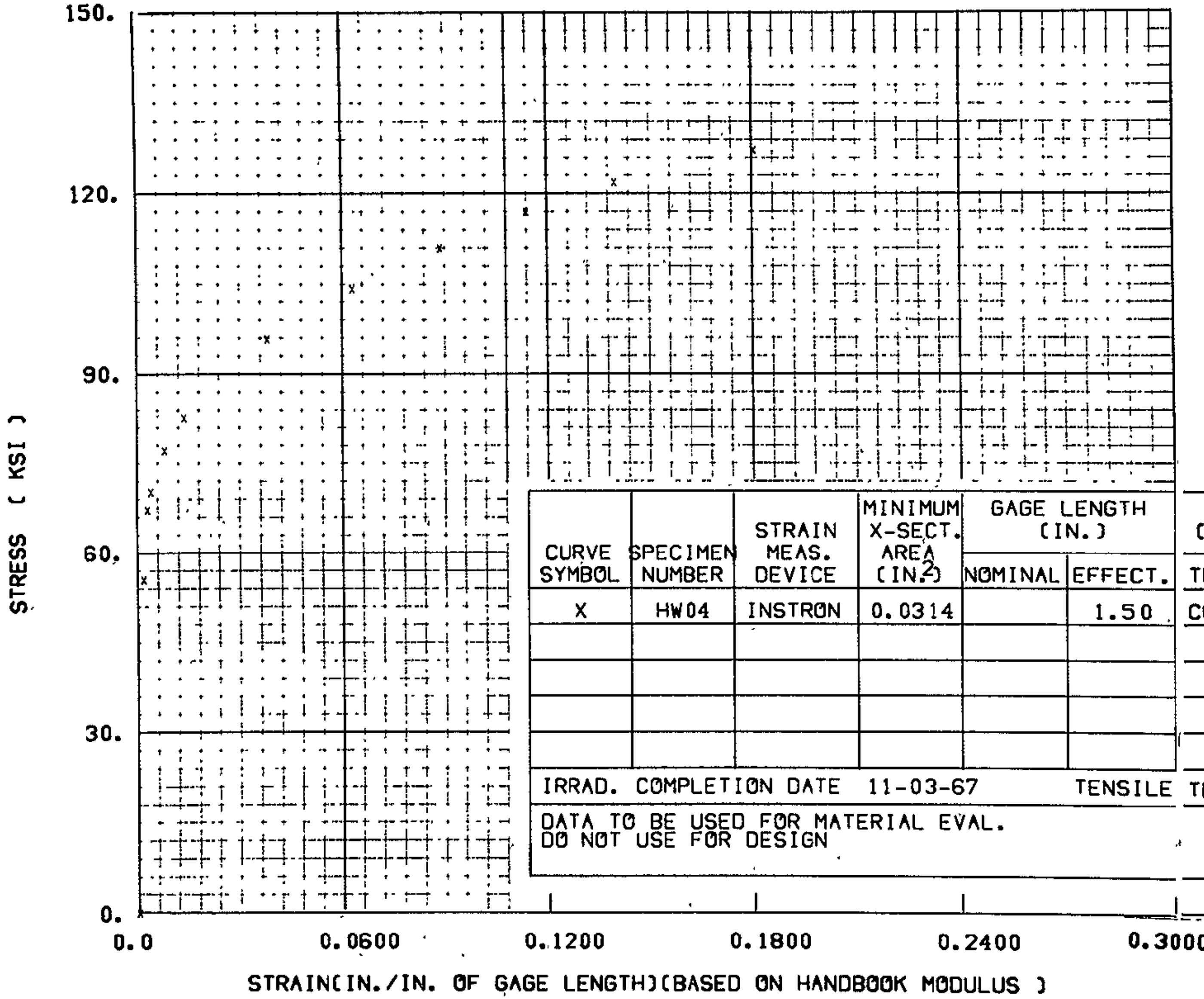
CURVE SYMBOL	SPECIMEN NUMBER	STRAIN MEAS. DEVICE	MINIMUM X-SECT. AREA (IN.^{2})	GAGE LENGTH (IN.) NOMINAL	GAGE LENGTH (IN.) EFFECT.	FLUENCE (NEUTRONS/CM^2) THERMAL	FLUENCE (NEUTRONS/CM^2) FAST	GAMMA DOSE (ERGS/GM(C))
X	HW01	INSTRON	0.0315		1.50	CONT		
+	HW02	INSTRON	0.0311		1.50	CONT		
*	HW03	INSTRON	0.0314		1.50	CONT		
0	HW04	INSTRON	0.0314		1.50	CONT		

IRRAD. COMPLETION DATE 11-03-67 TENSILE TEST DATE DEC. 67

DATA TO BE USED FOR MATERIAL EVAL.
DO NOT USE FOR DESIGN

FIGURE 4-41 STRESS-STRAIN CURVES FOR AS-WELDED HASTELLOY X AT 140 R. CONTROLS

NPC 26,803



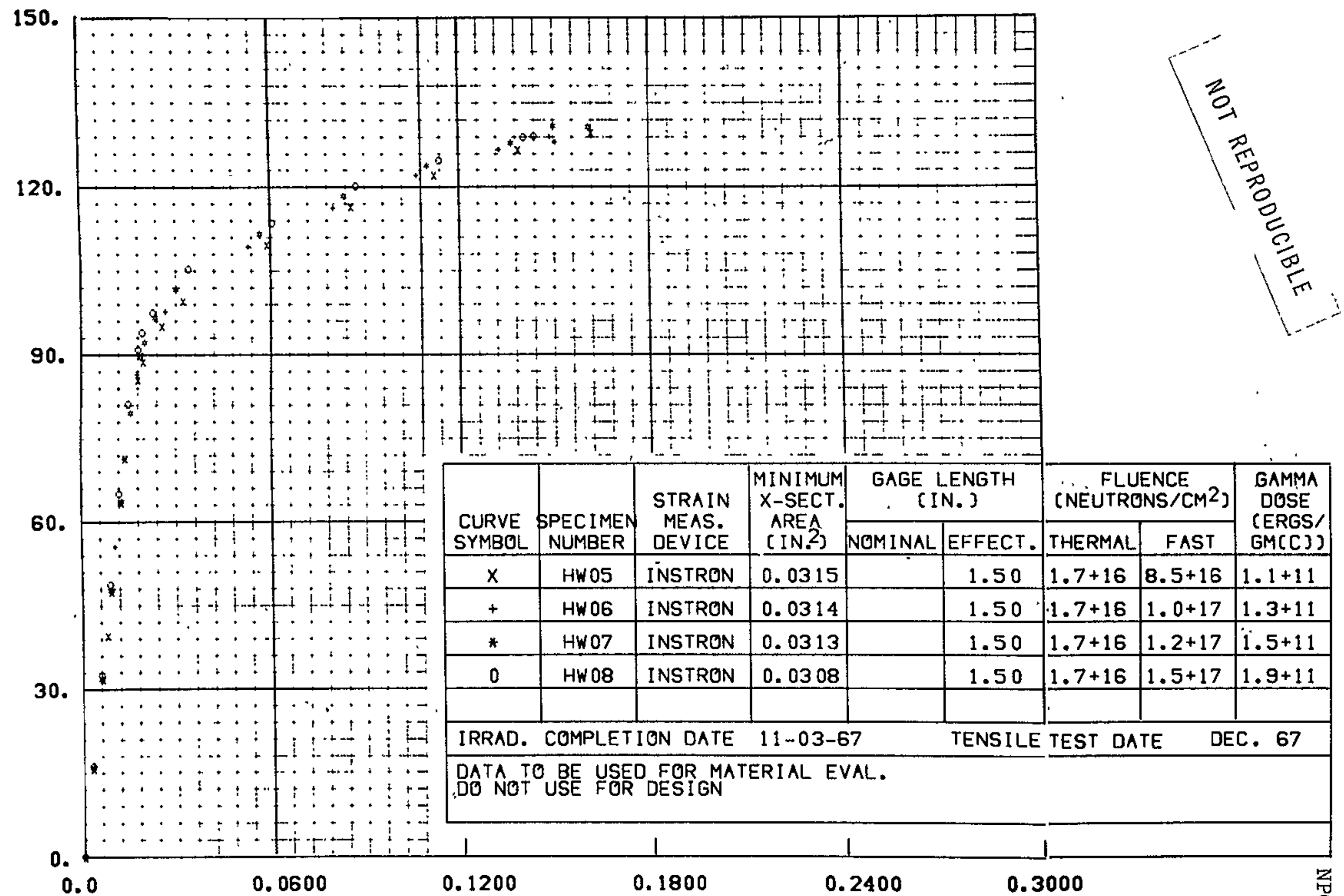
CURVE SYMBOL	SPECIMEN NUMBER	STRAIN MEAS. DEVICE	MINIMUM X-SECT. AREA (IN.^{2})	GAGE LENGTH (IN.) NOMINAL	GAGE LENGTH (IN.) EFFECT.	FLUENCE (NEUTRONS/CM^2) THERMAL	FLUENCE (NEUTRONS/CM^2) FAST	GAMMA DOSE (ERGS/GM(C))
X	HW04	INSTRON	0.0314		1.50	CONT		

IRRAD. COMPLETION DATE 11-03-67 TENSILE TEST DATE DEC. 67

DATA TO BE USED FOR MATERIAL EVAL.
DO NOT USE FOR DESIGN

FIGURE 4-42 STRESS-STRAIN CURVE FOR AS-WELDED HASTELLOY X FITTED TO HANDBOOK MODULUS. CONTROL

NPC 26,804



CURVE SYMBOL	SPECIMEN NUMBER	STRAIN MEAS. DEVICE	MINIMUM X-SECT. AREA (IN.^{2})	GAGE LENGTH (IN.)		FLUENCE (NEUTRONS/CM^2)		GAMMA DOSE (ERGS/ GM(C))
				NOMINAL	EFFECT.	THERMAL	FAST	
X	HW05	INSTRON	0.0315		1.50	1.7+16	8.5+16	1.1+11
+	HW06	INSTRON	0.0314		1.50	1.7+16	1.0+17	1.3+11
*	HW07	INSTRON	0.0313		1.50	1.7+16	1.2+17	1.5+11
0	HW08	INSTRON	0.0308		1.50	1.7+16	1.5+17	1.9+11

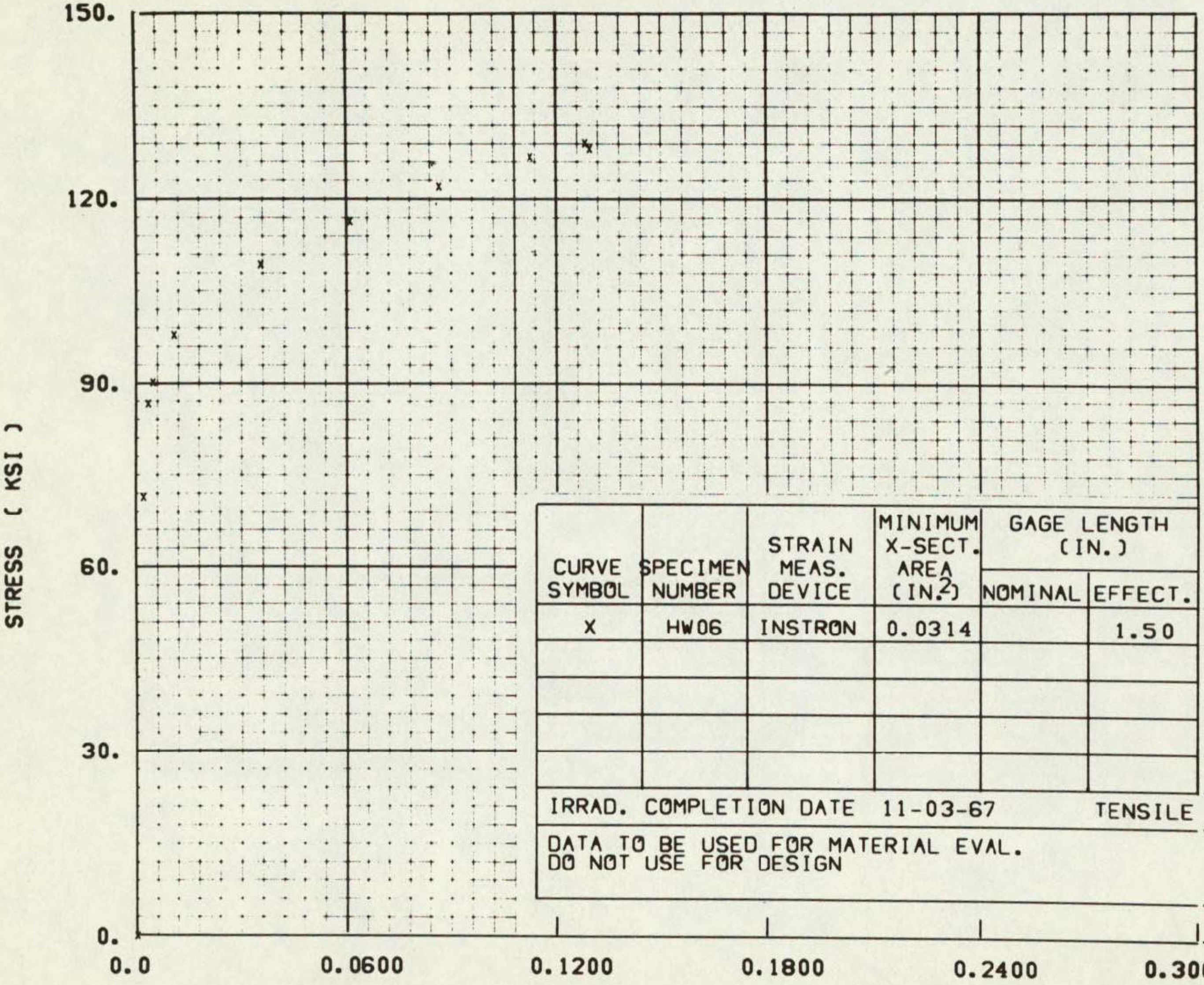
IRRAD. COMPLETION DATE 11-03-67 TENSILE TEST DATE DEC. 67

DATA TO BE USED FOR MATERIAL EVAL.
DO NOT USE FOR DESIGN

STRAIN (IN./IN. OF GAGE LENGTH)(BASED ON CROSSHEAD TRAVEL)

FIGURE 4-43 STRESS-STRAIN CURVES FOR AS-WELDED HASTELLOY X AT 140 R. IRRADIATED IN LN

NPC 26,805



CURVE SYMBOL	SPECIMEN NUMBER	STRAIN MEAS. DEVICE	MINIMUM X-SECT. AREA (IN.^{2})	GAGE LENGTH (IN.)		FLUENCE (NEUTRONS/CM^2)		GAMMA DOSE (ERGS/GM(C))
				NOMINAL	EFFECT.	THERMAL	FAST	
X	HW06	INSTRON	0.0314		1.50	1.7+16	1.0+17	1.3+11

IRRAD. COMPLETION DATE 11-03-67 TENSILE TEST DATE DEC. 67

DATA TO BE USED FOR MATERIAL EVAL.
DO NOT USE FOR DESIGN

STRAIN(IN./IN. OF GAGE LENGTH)(BASED ON HANDBOOK MODULUS)

FIGURE 4-44 STRESS-STRAIN CURVE FOR AS-WELDED HASTELLOY X FITTED TO HANDBOOK MODULUS. IRRADIATED IN LN

NPC 26,806

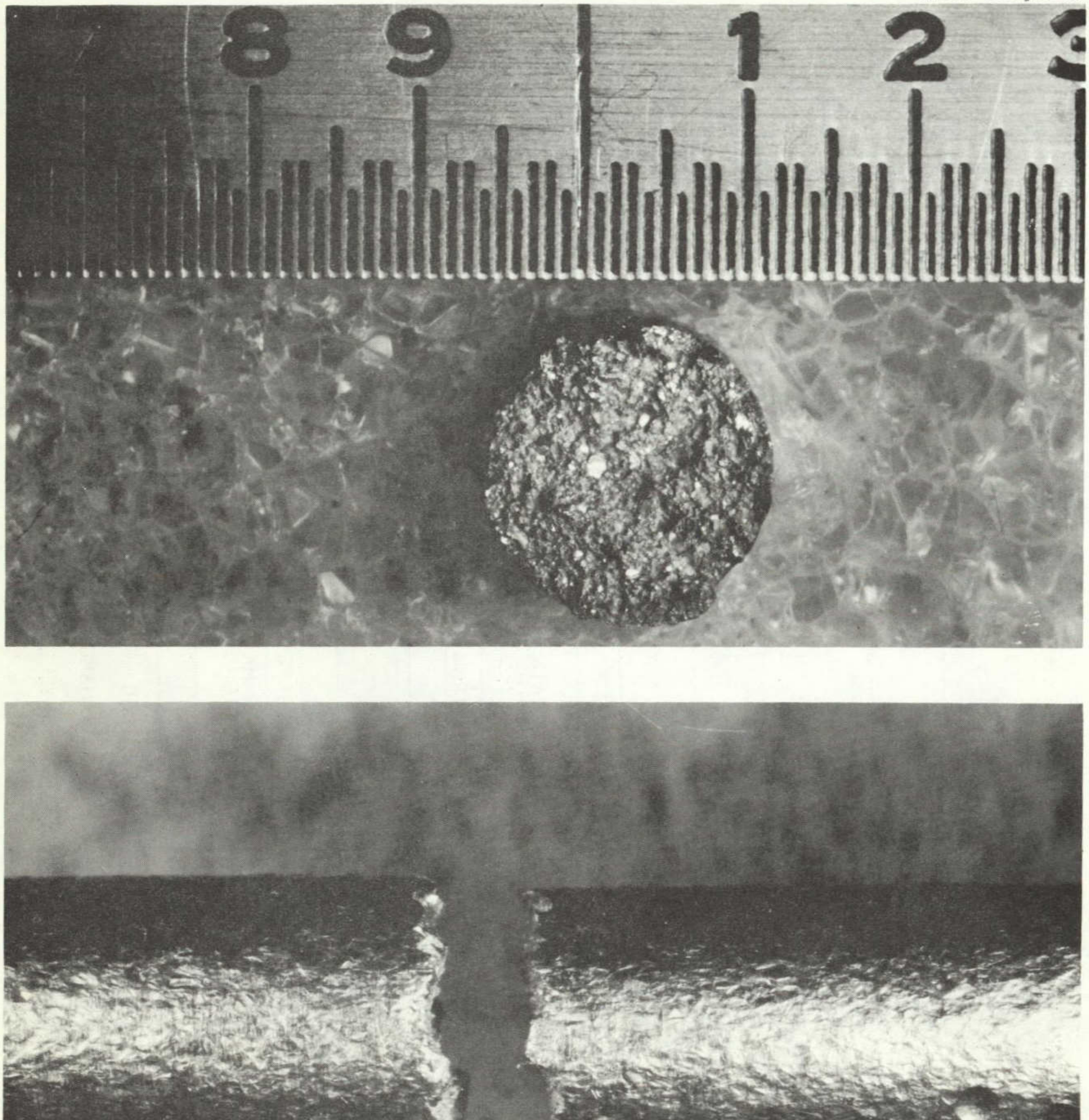


Figure 4-45 Macrograph (10X) of Hastelloy X, Specimen H-01: Control

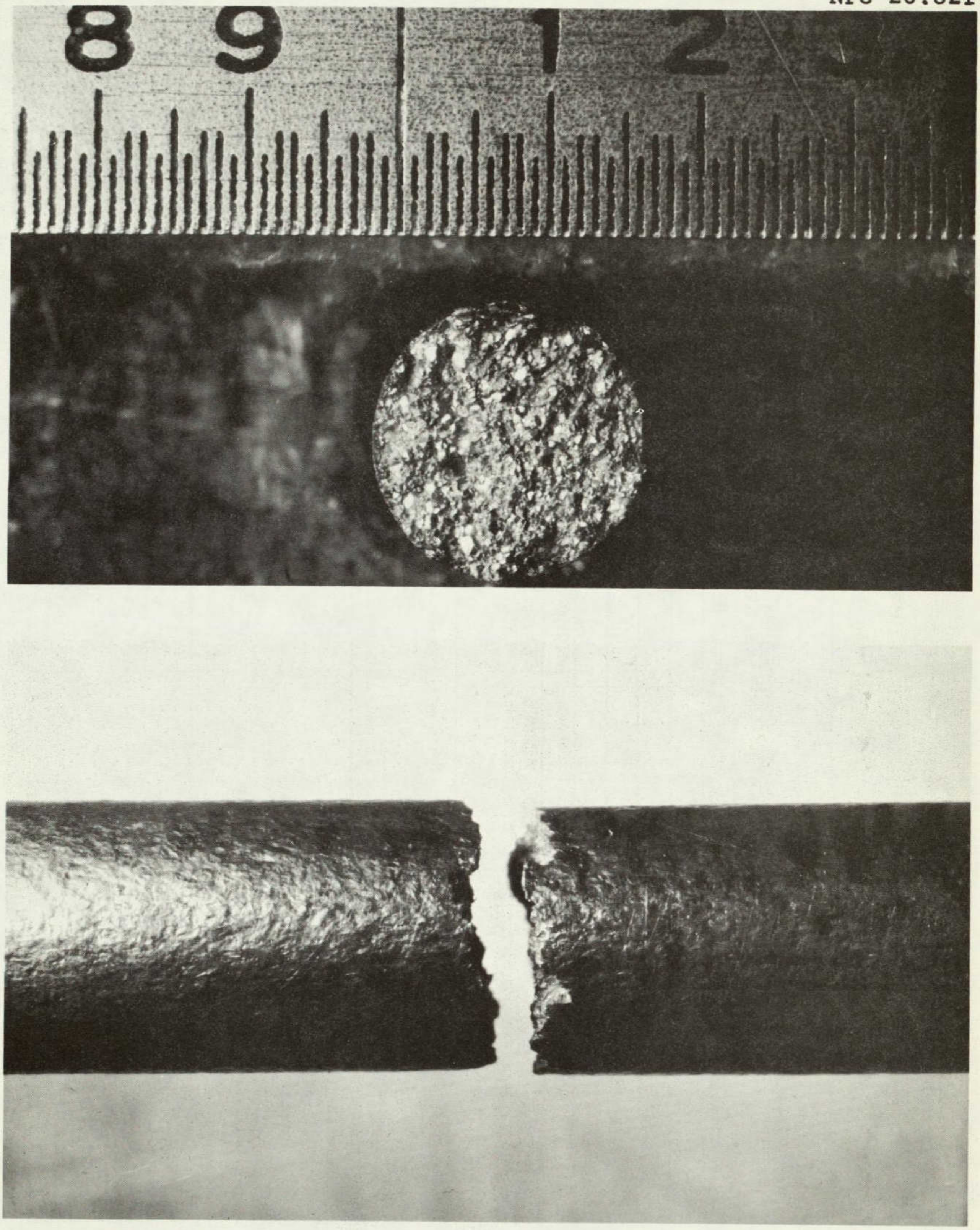


Figure 4-46 Macrograph (10X) of Hastelloy X, Specimen H-06: Irradiated at 140^{o}R

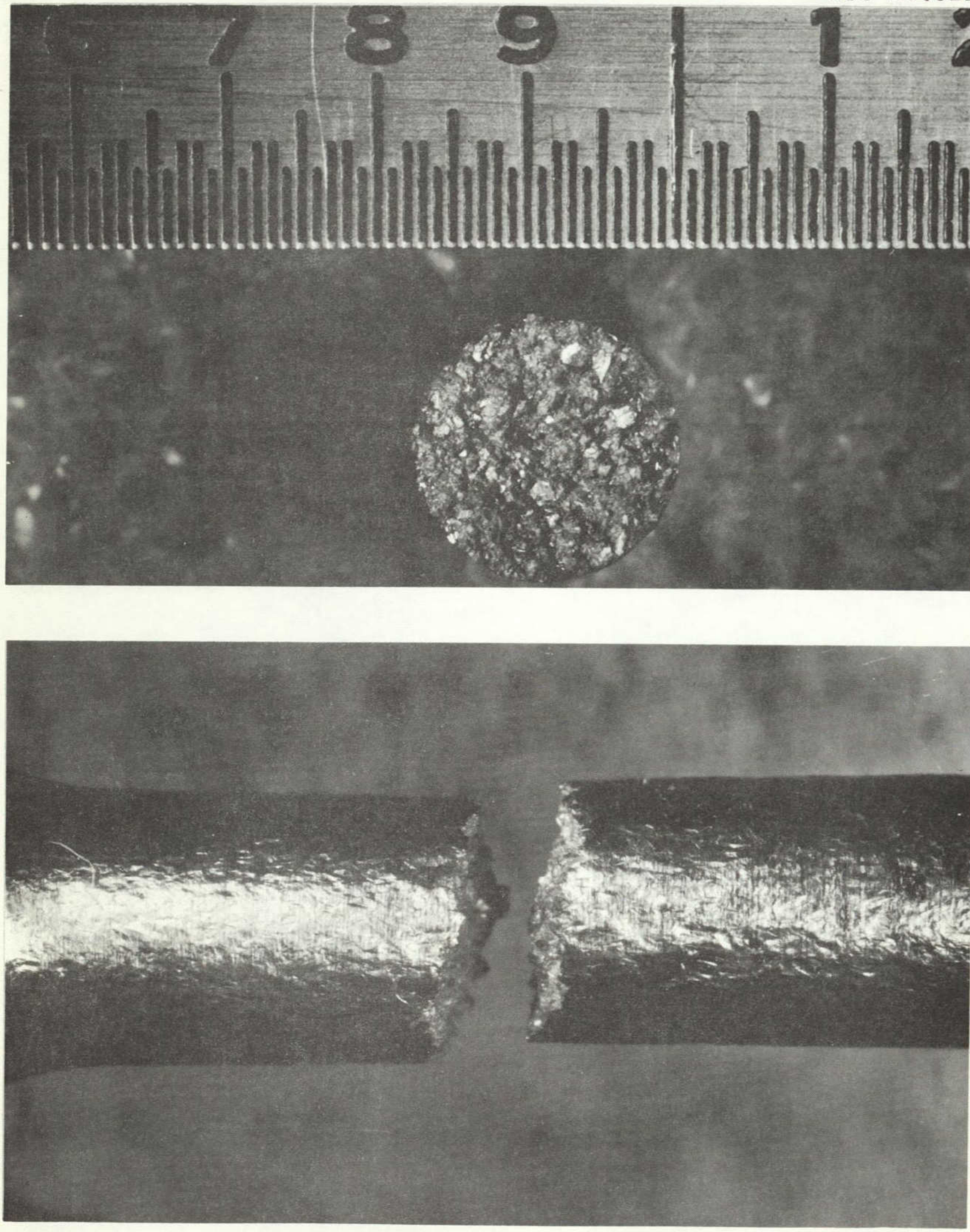


Figure 4-47 Macrograph (10X) of-Welded Hastelloy X, Specimen HW-04: Control

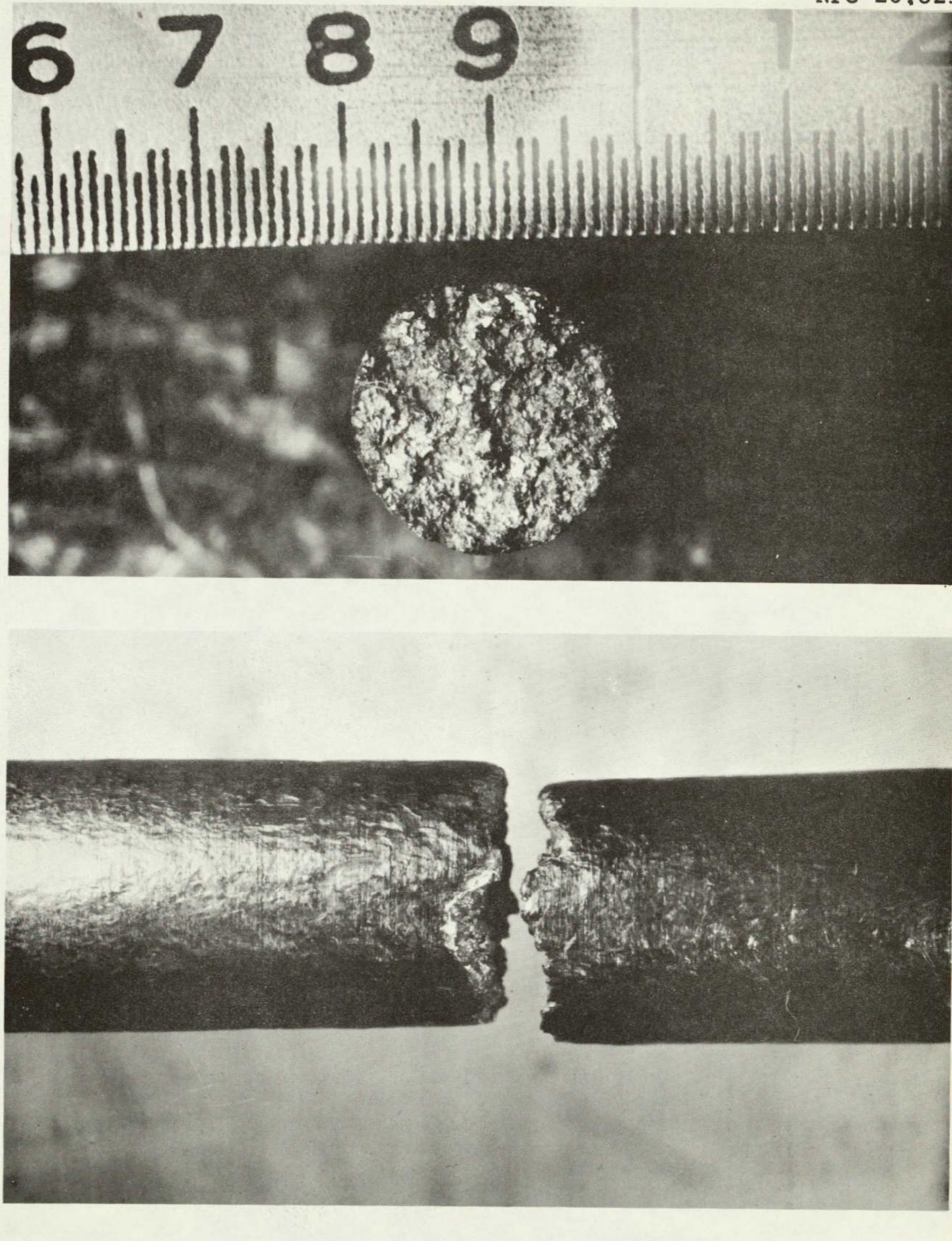


Figure 4-48 Macrograph (10X) of As-Welded Hastelloy X, Specimen HW-07: Irradiated at 140°R

V. TEST PROGRAM FOR HIGH-TEMPERATURE STRUCTURAL MATERIALS

The purpose of this experiment was to determine the effects of thermal-neutron exposure on the high-temperature tensile and stress-rupture properties of several nickel-base superalloys. Specimens fabricated from René 41, Waspaloy, and Inconel 718 were irradiated, while submerged in water, to three levels of neutron fluence and subsequently tensile-tested at several elevated temperatures. Some data were also taken with strain-rate as a test variable. Notched and unnotched specimens of Waspaloy and Inconel 718 irradiated to three levels of neutron fluence were stress-rupture-tested at an elevated temperature.

The GTR served as the mixed-field radiation source for this test (see Appendix E). The specimens were irradiated in a rack mounted on the pool side (south) of the GTR frame; the water temperature was about 580°R. Total reactor operating time during the irradiation (13 Oct-3 Nov 1967) was 2310 MWh (see Appendix A).

Upon completion of the irradiation, the specimens were transferred to the IML where tensile and stress-rupture tests were performed in accordance with specifications supplied by AGC.

5.1 Test Materials and Specimens

Waspaloy, René 41, and Inconel 718 are nickel-base alloys having many aerospace applications that require high strength and corrosion resistance at extreme temperatures. Background information on the stock materials and the specimen processing was provided by AGC and is given in Table 5-1. Chemical analyses (also provided by AGC) are presented in Table 5-2.

Tensile test specimens of René 41, Waspaloy, and Inconel 718 (37 ppm boron) were of a round-unnotched configuration fabricated according to AGC Drawing 1134298-1 (Fig. 3-1). Inconel 718 specimens with 0.6 ppm boron and 46 ppm boron corresponded to AGC Drawings 1134298-3 and 1134298-5, respectively (Fig. 3-1).

Stress-rupture test specimens were of two basic types: round-unnotched (Fig. 3-1) and combination-notched. The configuration of the latter type is shown in Figure 5-1 and conforms to AGC Drawing 1134453; typical stress-rupture specimens are shown in Figure 5-2.

Identification codes of the test specimens consisted of either one or two alphabetic characters, which identified the material and condition, followed by two or three digits designating the specimen number. The specimen identification code was engraved on both ends of each specimen.

Identification codes for the test materials are:

Material and Condition	Code
René 41, forging	R
Waspaloy, forging	W WS (combination type)
Inconel 718,	
37 ppm boron, forging	N NS (combination type)
46 ppm boron, forging	C
0.6 ppm boron, bar	L

Table 5-1

DESCRIPTION OF RENÉ 41, WASPALOY, AND INCONEL 718 STOCK AND SPECIMEN PROCESSING[a]

Forged or Rolled Stock as Received						Specimen Processing				
Code	Material	Vendor	Form and Dimensions	Heat Treat	Specification	Parent/ Welded	Anneal	Age	Specification	Hardness
R	René 41	Viking Forge and Steel Co.	Pancake Forging 22" Dia. x 2½"	Annealed at 1975°F	AMS 5712	Parent	Stabilized at 1550°F	1400°F - 16 Hours	AMS-5712	39 R_C
W	Waspaloy	Viking Forge and Steel Co.	Pancake Forging 22" Dia. x 2½"	Annealed at 1950°F Stabilized at 1550°F Aged at 1400°F	AGC 44006D	Parent	Original by Forger	Original by Forger	AGC-44006	36 R_C
N	Inconel 718	Wyman-Gordon Co.	Rotor Turbine Forging	Annealed at 1800°F	AGC 44098 Am.#1	Parent	Original by Forger	1325°/1150°F Total Time, 18 Hours	AGC-46626	43 R_C
C	Inconel 718	Reisner Metals Inc.	Ring Forging 23" O.D. x 21½" I.D. x 4.7"	Annealed at 1950°F	AGC 44194 and 44098	Parent	Original by Forger	1350°/1200°F Total Time, 20 Hours	AGC-46604	42 R_C
L	Inconel 718	ALLVAC Metals Co.	Bar Low Boron 3/4" x 3/4"x72"	Annealed at 1800°F	AGC 46626 and 90093	Parent	Original by Forger	1325°/1150°F Total Time, 18 Hours	AGC-46626	43 R_C

[a]Data provided by AGC

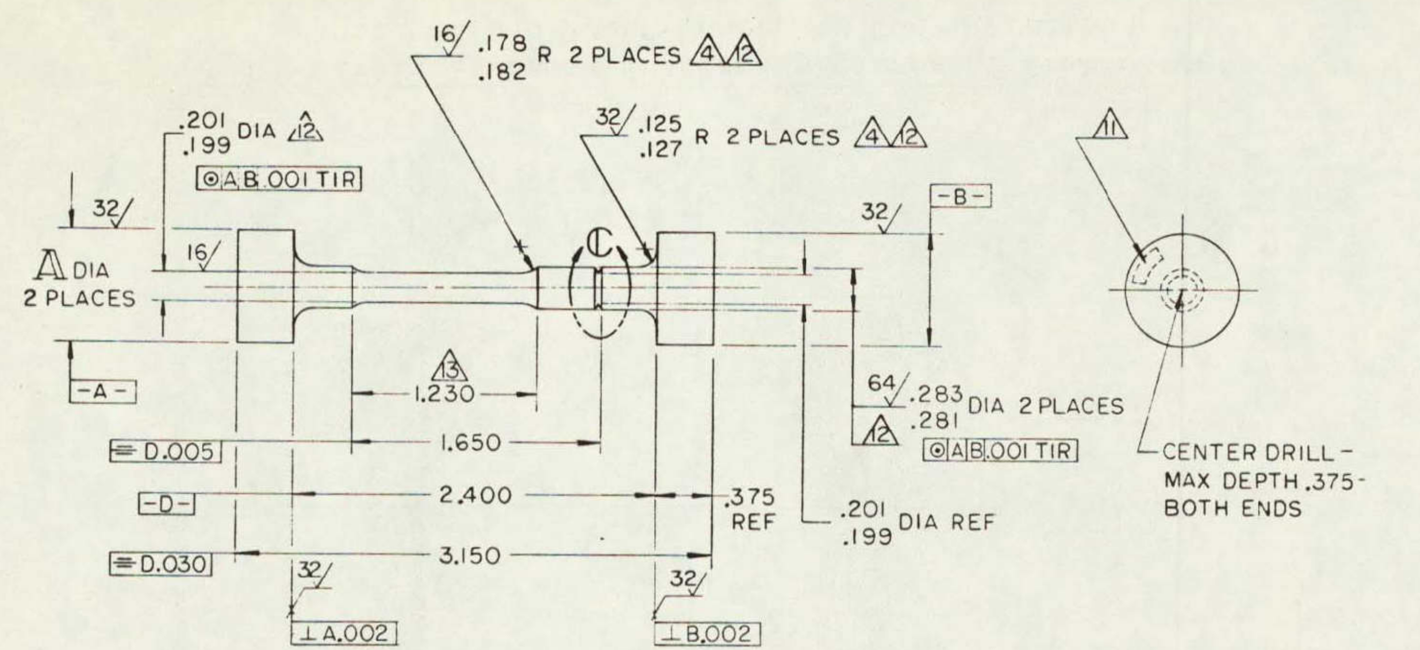
Table 5-2

CHEMICAL ANALYSIS OF RENÉ 41, WASPALOY, AND INCONEL 718[a]

Material		Element (% by weight)															
		Ni	Mo	Cr	Fe	C	Cb+Ta	Mn	Si	Al	Ti	Zr	Cu	Co	P	S	B
Inconel 718	Rotor Turbine Heat C-57226	54.3	2.83	18.7	Bal	0.050	5.19	0.04	0.077	0.59	0.98		0.02	0.05	0.005	0.004	0.0037[b]
	Ring Heat 8289	53.3	3.10	18.50	Bal	0.05	5.25	0.10	0.18	0.50	1.05		0.10	0.10	0.01	0.003	0.0046
	Bar Heat D-284	52.70	2.98	18.88	Bal	0.043	4.83	0.05	0.09	0.47	0.90		0.02	0.03	0.004	0.007	0.00004
René 41	Disc Forging Heat 6472	Bal	9.83	18.80	0.50	0.077		0.02	0.06	1.57	3.17			10.95		0.006	0.0050[b]
Waspaloy	Disc Forging Heat 6462	Bal	4.27	18.82	0.78	0.048		0.02	0.06	1.31	3.04	0.063	0.02	13.6	0.008	0.006	0.0047[b]

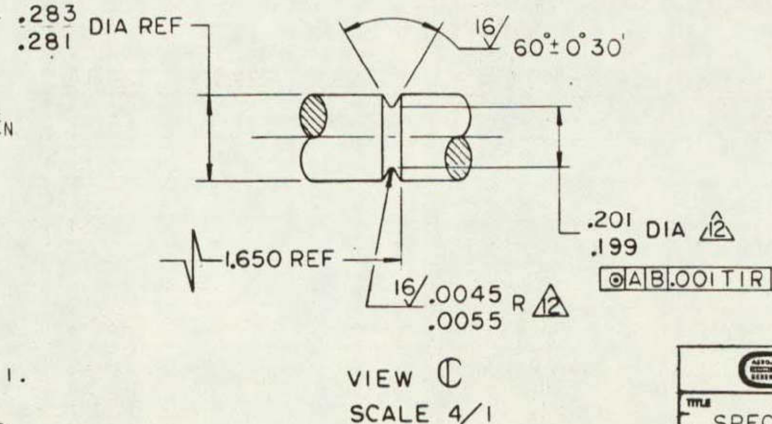
[a]Data provided by AGC

[b]Analysis by Ledoux & Co.



NOTES:

1. INTERPRET DRAWING PER STANDARDS PRESCRIBED IN MIL-D-1000.
2. REMOVE ALL BURRS AND SHARP EDGES EQUIVALENT TO .005 - .015 R. UNLESS OTHERWISE NOTED.
3. SURFACE ROUGHNESS 125/ UNLESS NOTED.
4. SMOOTH TRANSITION IS REQUIRED BETWEEN ALL INTERSECTING RADII AND SURFACES TANGENT TO RADII.
5. MARK PER ASD5215M WITH 1134453 & APPLICABLE DASH NO.
6. MATERIAL, TREATMENT, FINISH AND IDENTIFICATION TO BE DETERMINED BY COGNIZANT ENGINEEER.
7. IF PART IS WELDED, RADIOGRAPHIC INSPECT WELDS PER AGC-STD-1151. ACCEPT PER AGC-STD-4005 CL. I.
8 PENETRANT INSPECT PER AGC-STD-3010. ACCEPT PER AGC-STD-4005, CL. I.
9. CLEANLINESS PER AGC-STD-9007, LEVEL I.
10. PRESERVE AND PACKAGE PER AGC-46387, CLASS I.
11. MARK PER ASD5215C OR D WITH SERIAL NO. PROVIDED BY COGNIZANT ENGINEER.
12. THESE DIMENSIONS TO BE INSPECTED AND RECORDED. INSPECTION RECORDS SHALL BE MARKED WITH PART SERIALIZATION NO.
13. NO DIA IN THIS SECTION MAY BE LESS THAN THAT MEASURED AT THE CENTER OF DIMENSION 1.230.



DASH NO.	A DIA
-1	.751/.749
-3	.626/.624
-5	.701/.699

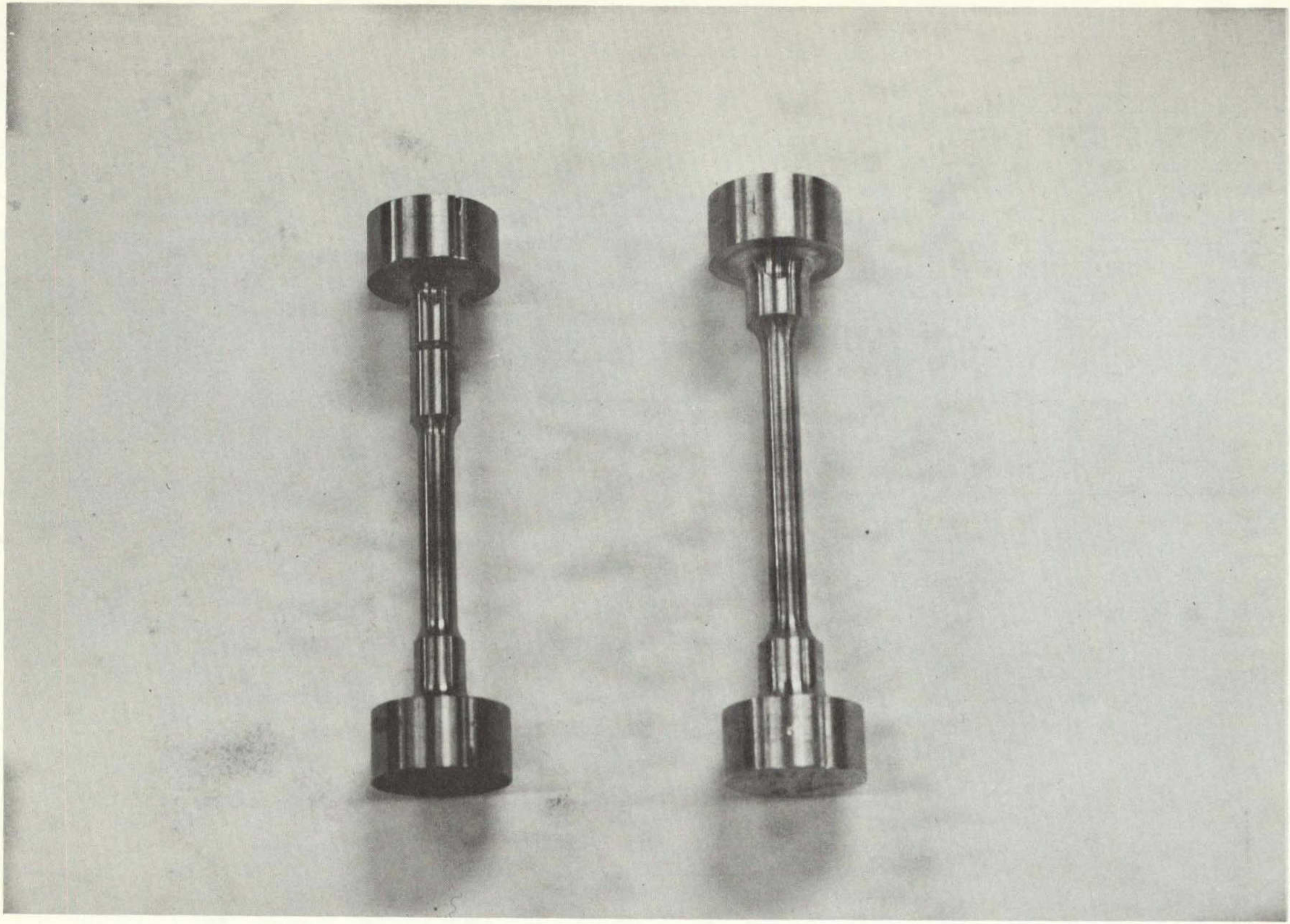
AEROJET-GENERAL CORPORATION
SACRAMENTO, CALIFORNIA

TITLE: SPECIMEN-STRESS RUPTURE, BUTTONHEAD-AMS 5735

DWG SIZE	CODE IDENT NO.	DWG. NO.
D	05824	1134453

SCALE 2/1 | RELEASE DATE 7/21/67 | SHEET

Figure 5-1 Configuration of High-Temperature Stress-Rupture Combination-Notched Specimens (AGC Drawing 1134453)



NPC 26,824
31-9492

Figure 5-2 Typical Stress-Rupture Specimens of Combination-Notched and Round-Unnotched Configurations

5.2 Test Equipment and Instrumentation

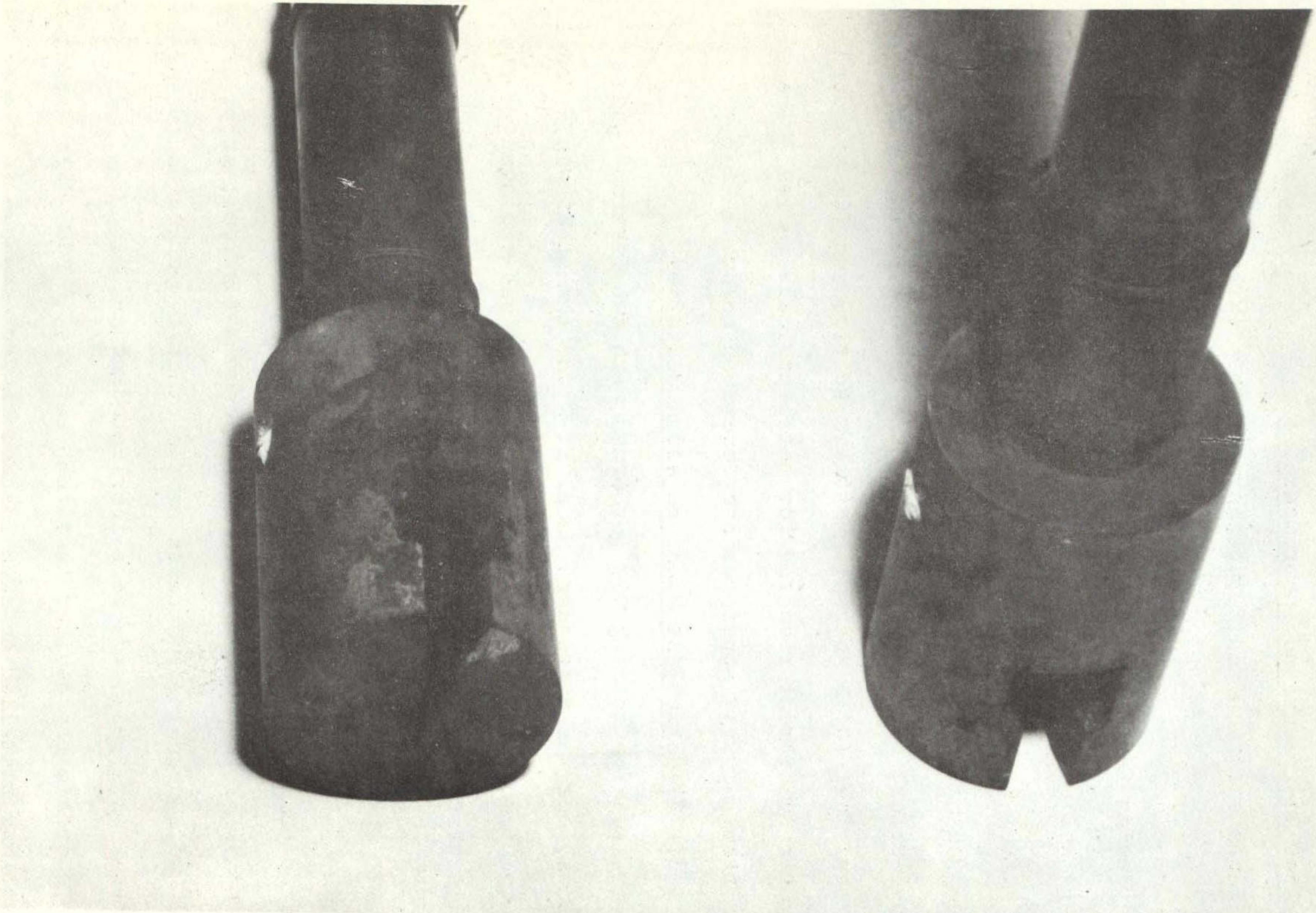
Equipment required for performing this experiment consisted of (1) a rack for containing and mounting the specimens on the GTR frame during irradiation, (2) tensile test machines and associated heaters and components for testing specimens at temperatures to 1860°R, (3) Riehle creep-testing machines and associated heaters and components for stress-rupture tests at temperatures to 1860°R, (4) an optical comparator for determination of specimen dimensions after testing, (5) a Rockwell hardness tester, and (6) standard laboratory equipment required for metallurgical studies. The major items of test apparatus are described below.

5.2.1 Tensile Test Machines and Accessories

The tensile testing was performed with two Instron test machines; one was a standard Model TT-C and the other was a Model TT-D split-console type. The latter machine was employed in the tensile tests performed at 1660°R while the standard model was utilized for the tests at 1360°, 1510°, 1585°, 1760°, and 1860°R.

A set of the René 41 specimen grips used for testing at elevated temperatures is shown in Figure 5-3. Grips S/N 11 and 12 were used for the 1660°R test (split-console Instron); grips S/N 9 and 10 were used for the tests at the other temperatures (standard Instron). All pull rods were fabricated of A-286.

To obtain the desired test temperatures, a 2000-watt Marshall furnace was installed on each Instron tester as shown in Figure 5-4.



NPC 26,825
31-9493

Figure 5-3 Grips Used in Tensile Tests at Elevated Temperatures

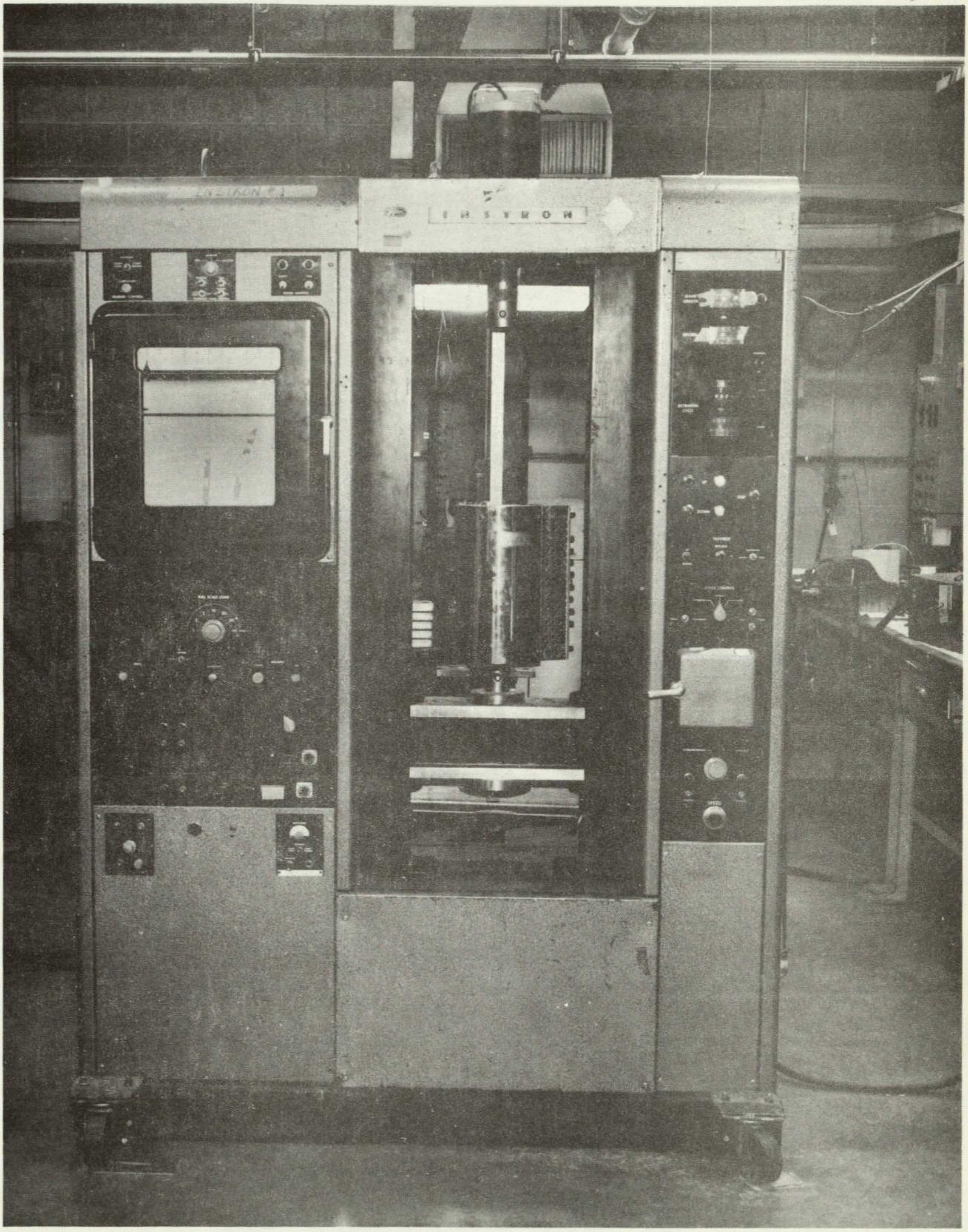


Figure 5-4 Instron with Oven in Test Position

Temperature controllers were of the ON-OFF type; an Instron controller was used with the Model TT-D Instron and Marshall Control Panel, Model 4049-40F, was used with the Model TT-C Instron. The calibration procedure is described in Section 5.3.2.

5.2.2 Stress-Rupture Testers

The stress-rupture specimens were tested on two Model CR-20 Riehle Creep Rupture Testing Machines having a capacity of 20,000 lb. Each machine is a dead-weight type with a single overhead lever having a 20:1 ratio. The specimen is placed under load by adding loading weights to the beam pan. Accuracy is within 0.5% of the load.

Each machine is equipped with two self-aligning ball-seated clevises which allow freedom of motion on both axes so that bending moments on the specimen are reduced to a minimum. Creep-measuring and temperature-control equipment are integrated into the machines.

Creep-Measuring Equipment. Each Riehle is equipped with creep-measuring instrumentation which includes an LVDT-type extensometer and a recording unit. The instrumentation system is shown schematically in Figure 5-5.

An important criterion in the design of the test specimens and specimen grips was to minimize personnel exposure to the highly radioactive test specimens. A consequence of the resulting specimen/grip configuration was that the extensometer could not be

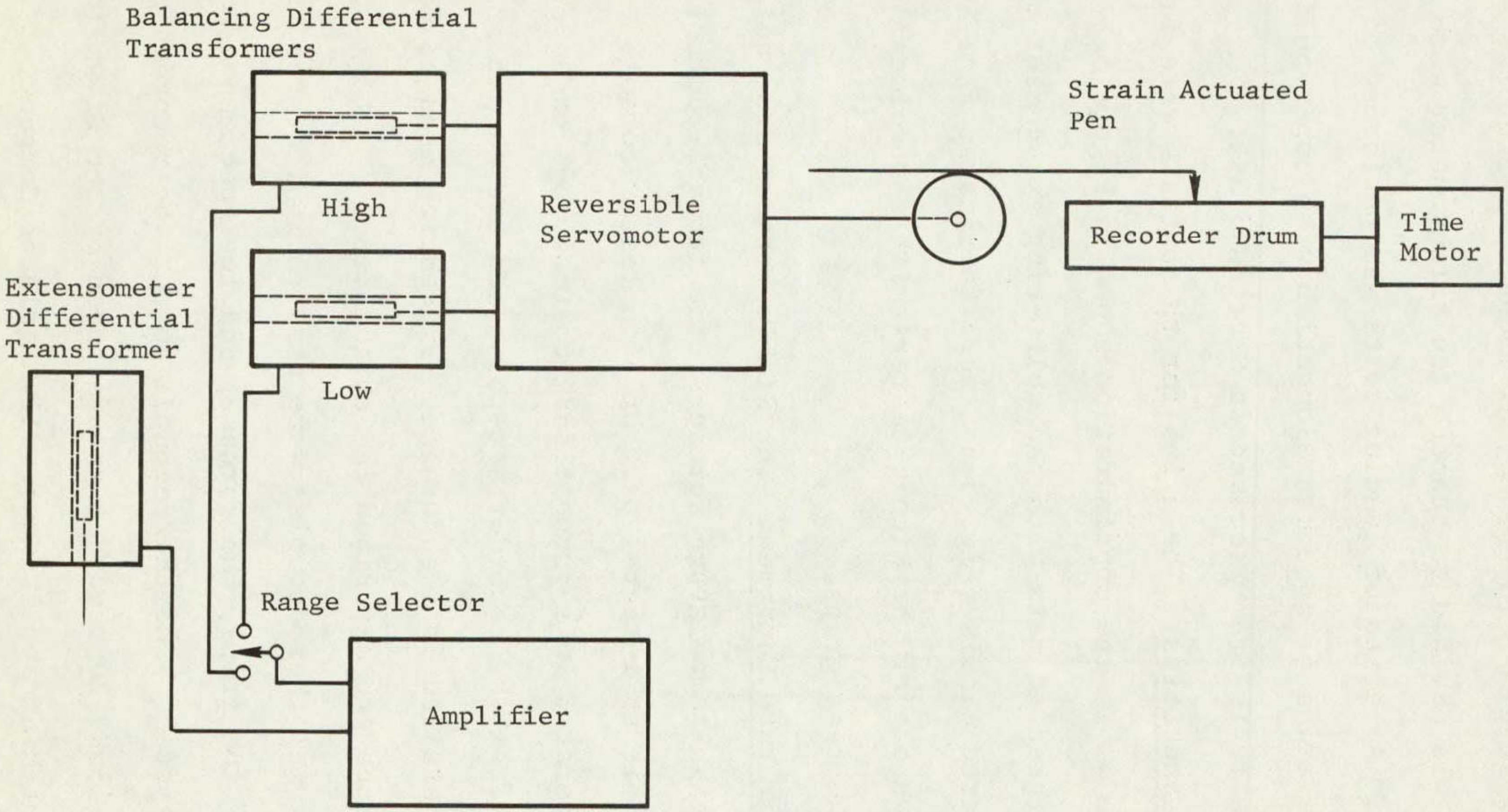


Figure 5-5 Schematic of Riehle Creep-Time Recorder

NPC 26,827

attached to the specimen in the normal manner. Therefore, a linkage system was devised to connect the extensometer with the upper pull rod. A series of loading tests was performed to establish correlation of specimen elongation with upper-pull-rod movement; these tests are discussed in Section 5.3.3.

Pull Rods and Grips. The grips for these tests were fabricated from René 41 in the configuration shown in Figure 5-3. The pull rods, designed to mate with the split-ring attachment of the Riehle ball-seated clevis (Fig. 5-6), were fabricated from A-286. Figure 5-7 shows one of the Riehle testers with a specimen installed in the test grips.

High-Temperature Equipment. The Riehle testers are equipped with Marshall high-temperature furnaces; the furnace-control instrumentation is an integral part of each tester console. The furnaces are operated in a proportional-control mode on an error signal derived from the recorder set-point and the output of a thermocouple installed in the furnace. Procedures used to calibrate the furnaces are described in Section 5.3.3.

Chromel-alumel thermocouples were used to monitor the temperature of each of the grips, the furnace, and the specimen used to calibrate the system. The thermocouple output was recorded on a Model 153R10PS-135K1-20 recorder manufactured by the Brown Instrument Division of Minneapolis-Honeywell Regulator Company.

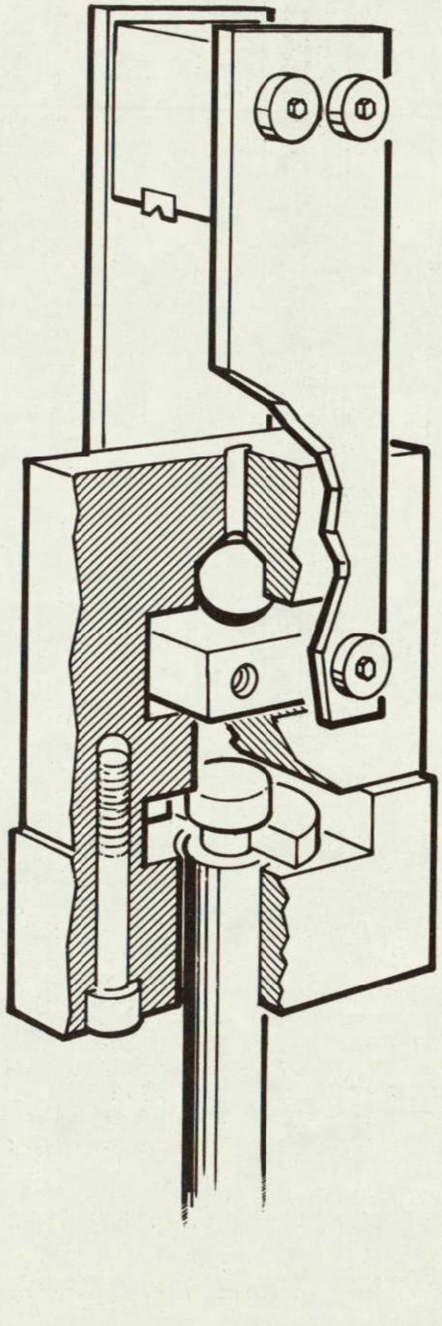


Figure 5-6 Schematic of Riehle Ball Clevis

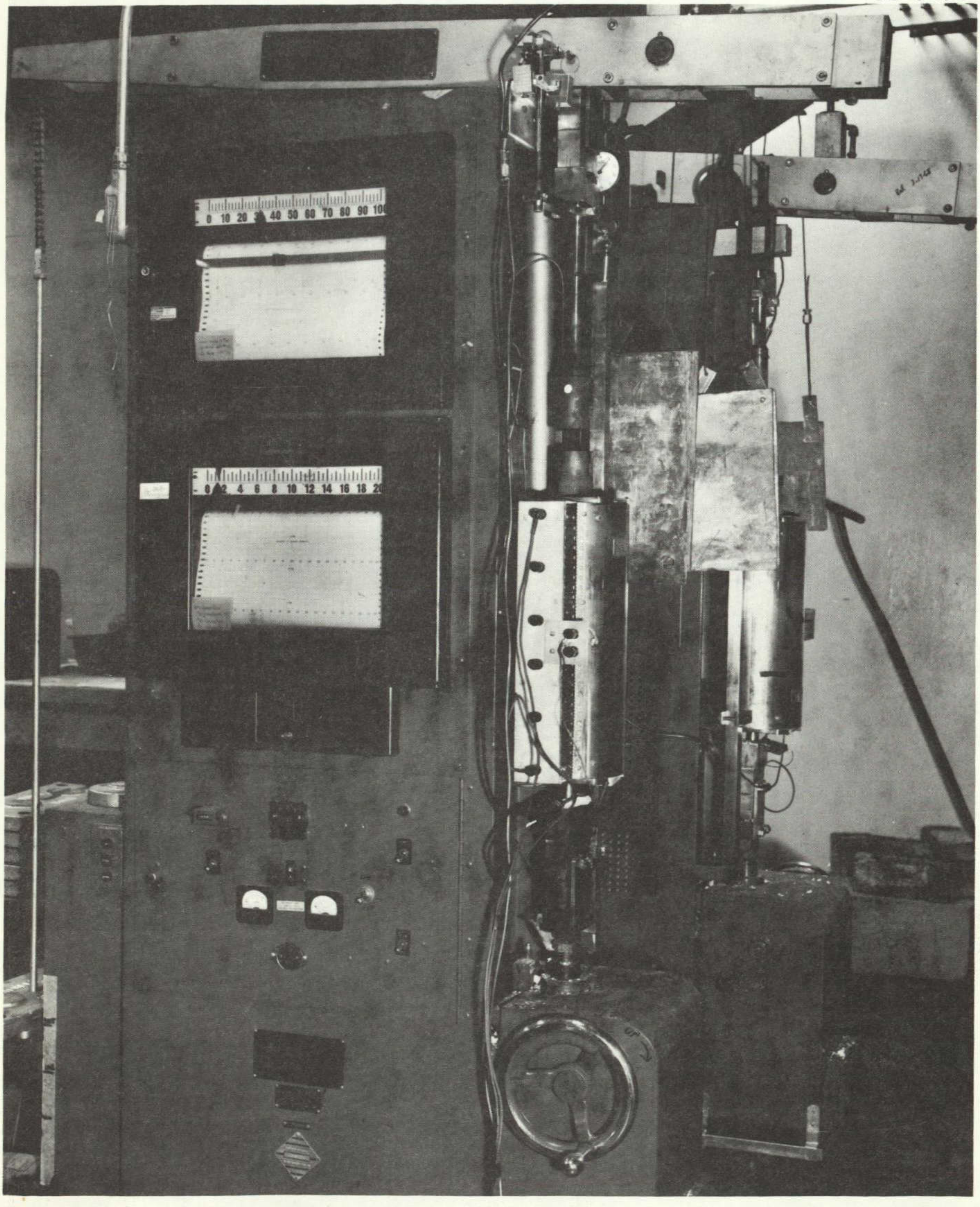


Figure 5-7 Riehle Tester and Associated Test Equipment

5.2.3 Optical Comparator

An optical comparator was used for determining final gage lengths and diameters of the specimens after fracture. The instrument used was a Bausch and Lomb Optical Comparator.

5.3 Test Procedures

5.3.1 Irradiation of Specimens

The specimen irradiation rack was designed to permit exposure of specimens to three different thermal-neutron fluences by grouping specimens at varying distances from the reactor core. The target fluences for the groups were 5×10^{18}, 5×10^{17}, and 1×10^{16} n/cm^2 ($E < 0.48$ eV). The specimen rack, shown in Figure 5-8, was attached to the south side of the GTR frame. The specimens were located on the rack in a plane coincident with a horizontal plane passing through the center of the core. The test-specimen arrangement in the irradiation rack is shown in Figure 5-9.

After completion of the irradiation (3 Nov 1967), the specimens were left on the GTR frame until preparations for tensile-testing in the IML were completed. The specimens were transferred to the IML on 14 February 1968. Tensile-testing was initiated on 4 March 1968 and completed on 2 April 1968. Stress-rupture tests were initiated on 19 March 1968 and completed on 8 June 1968.

5.3.2 Calibration of Tensile Test Equipment

Axiality Checks. The procedures for axiality determinations of the two Instron machines employed in this study were the same

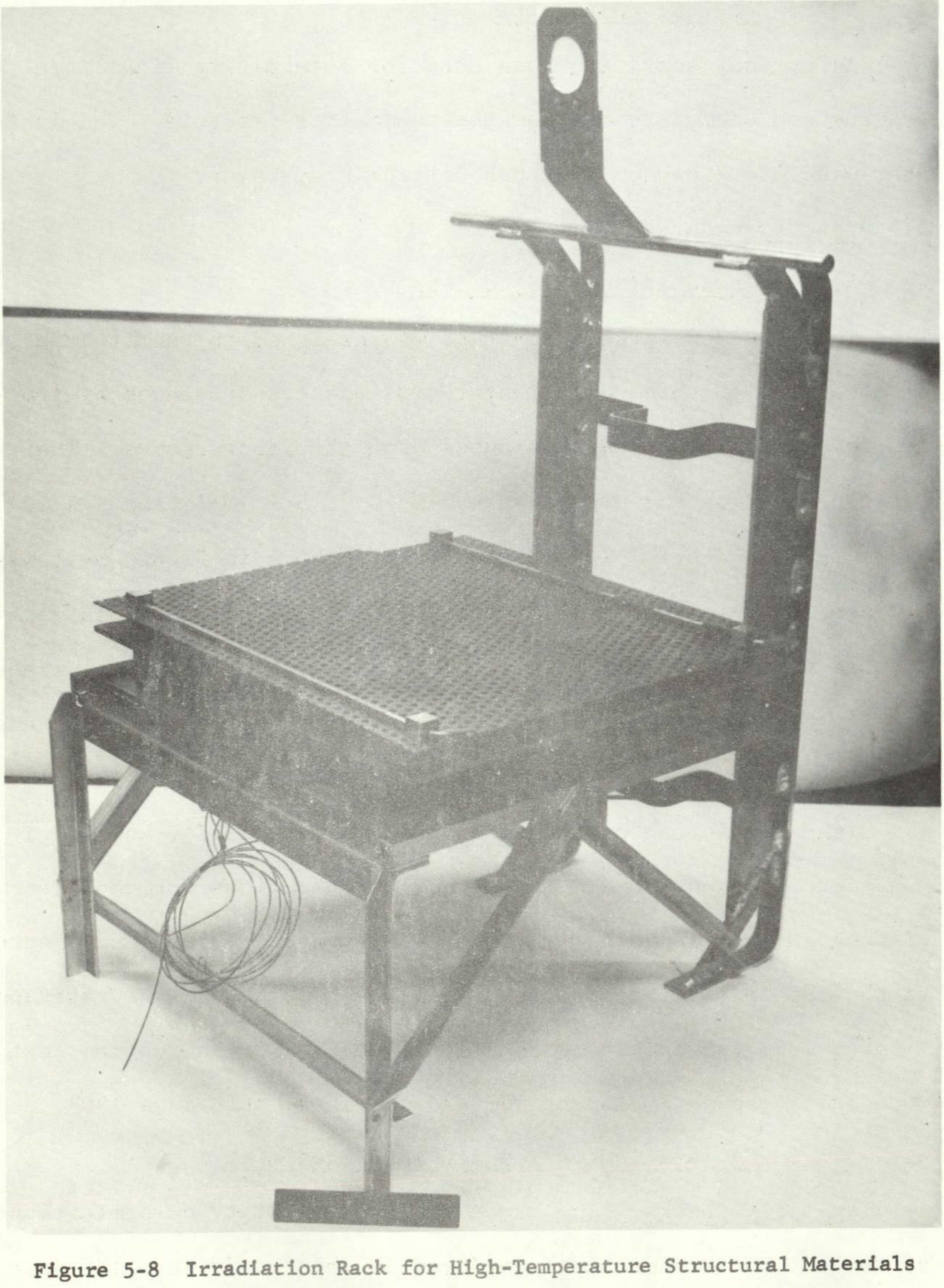


Figure 5-8 Irradiation Rack for High-Temperature Structural Materials

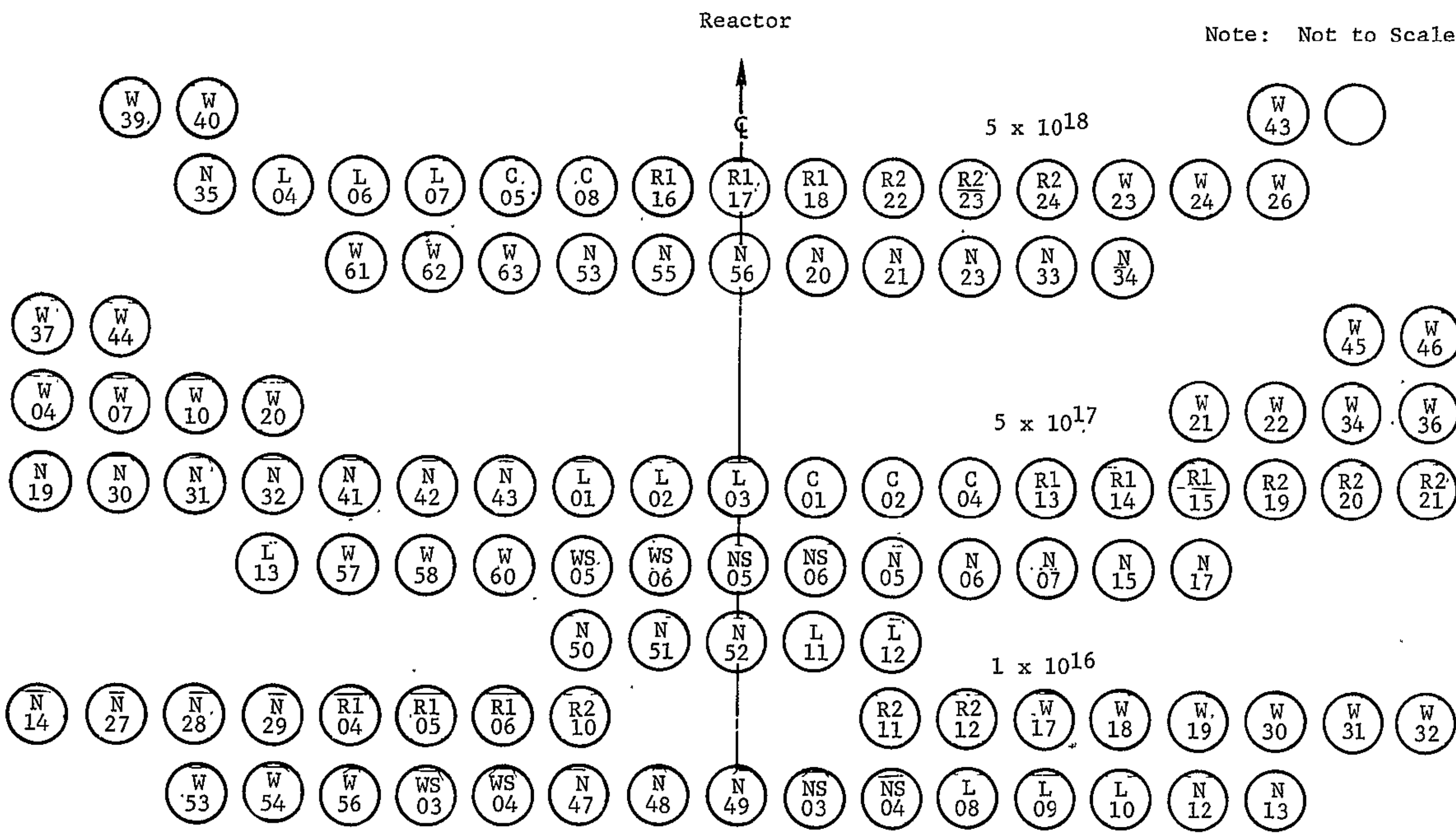


Figure 5-9 Arrangement of the High-Temperature Specimens in the Irradiation Rack.

NPC 26,831

as those described in Section 3.3.2. Axiality of both the standard model Instron and the split-console model was within 3% at a load of 3000 lb. The data are given in Tables 5-3, 5-4, 5-5, and 5-6.

Furnace Calibration. The temperature of the specimen during testing was controlled by monitoring and regulating the temperatures of the specimen grips. It was therefore necessary to calibrate the furnace in terms of grip temperatures corresponding to the desired specimen test temperatures. The furnace control system is illustrated in Figure 5-10; the calibration procedure was as follows:

1. Chromel-alumel thermocouples were embedded in both the upper and lower specimen grips.

2. A chromel-alumel thermocouple was resistance-welded to the center of the gage-length section of a specimen of the same configuration as that to be tested.

3. The thermocouple-instrumented specimen was then placed in the Instron grips and the furnace lowered into position.

4. Power was applied to the furnace. When the specimen-mounted thermocouple reached the desired test temperature, the furnace controller was set to maintain this temperature.

5. With the specimen temperature stabilized, the temperatures of the specimen grips were noted. This was repeated for each test temperature.

6. During the testing, the test temperatures of all tensile specimens were maintained by monitoring and controlling the temperatures of the upper and lower grips at the predetermined levels.

Table 5-3

AXIALITY DATA FOR INSTRON MODEL TT-D PRIOR TO HIGH-TEMPERATURE TESTS

Specimen: R2 25 (René 41) | 2 February 1968

Instron Load (lb)	Sanborn Scale Division Reading[a]						Maximum Deviation (%)
	0°	90°	180°	270°	Avg	Max Dev	
1000[b]	14.0	13.5	13.5	14.0	13.75	0.25	1.82
2000[b]	29.0	29.5	29.5	29.5	29.37	0.37	1.28
3000[b]	45.5	45.0	46.0	46.0	45.62	0.62	1.37
1000[c]	13.5	14.0	13.0	14.0	13.62	0.62	4.59
2000[c]	29.0	29.5	30.0	30.0	29.62	0.62	2.11
3000[c]	45.0	46.0	46.5	46.5	46.00	1.00	2.17
1000[d]	12.5	13.0	14.0	13.0	13.12	0.87	6.66
2000[d]	27.5	28.5	29.5	29.0	28.62	1.12	3.93
3000[d]	44.0	44.5	46.0	46.0	45.12	1.12	2.49

[a]To convert Sanborn Scale Division Reading to inches of extension, multiply given value by 62.5 microinches per division.

[b]Specimen in original position.

[c]Specimen rotated 90° from original position.

[d]Specimen inverted.

Table 5-4

AXIALITY DATA FOR INSTRON TT-C PRIOR TO HIGH-TEMPERATURE TESTS

Specimen: R2 25 (René 41) 2 February 1968

Instron Load (lb)	Sanborn Scale Division Reading[a]						Maximum Deviation (%)
	0°	90°	180°	270°	Avg	Max Dev	
1000[b]	13.5	13.5	14.0	13.5	13.62	0.37	2.75
2000[b]	29.5	30.0	30.0	29.5	29.75	0.25	0.84
3000[b]	46.5	47.0	47.5	46.5	46.87	0.62	1.33
1000[c]	13.5	13.5	13.5	13.0	13.37	0.37	2.80
2000[c]	29.5	29.5	29.5	29.5	29.5	0.00	0.0
3000[c]	46.5	46.5	47.0	46.0	46.5	0.50	1.08
1000[d]	13.5	14.0	14.0	13.0	13.62	0.62	4.59
2000[d]	30.0	31.0	30.5	29.5	30.2	0.75	2.48
3000[d]	47.0	47.5	47.5	47.5	47.37	0.37	0.79

[a]To convert Sanborn Scale Division Reading to inches of extension, multiply given value by 62.5 microinches per division.

[b]Specimen in original position.

[c]Specimen rotated 90° from original position.

[d]Specimen inverted.

Table 5-5

AXIALITY CHECKS FOR HIGH-TEMPERATURE TENSILE TESTS[a]

Instron Model	Specimen No.	Maximum Deviation[b] (%)	Date Performed
TT-D	R2 25	1.37	2-27-68
	L 05	3.31[c]	3-12-68
	L 05	2.95	3-15-68
	R2 25	2.57	3-26-68
TT-C	R2 25	1.33	2-28-68
	R2 25	1.25	3-15-68
	R2 25	1.77	3-27-68

[a]All checks performed at room temperature.

[b]Maximum deviation from the average of four readings around the circumference of the specimen at a load of 3000 lb unless otherwise stated.

[c]Load of 2250 lb.

Table 5-6

RELATIONSHIP OF INSTRON CROSSHEAD STRAIN TO EXTENSOMETER STRAIN IN THE ELASTIC REGION AT ROOM TEMPERATURE

Specimen type: round unnotched - AGC Dwg. 1134298-1
Specimen material: René 41

Instron Model	Instron Load (lb)	Crosshead Strain[a] (in./in.)	Extensometer Strain (in./in.)	Ratio: Crosshead/ Extensometer
TT-D	1000	0.0085	0.00088	9.67
	2000	0.0155	0.00181	8.56
	3000	0.0215	0.00284	7.57
TT-C	1000	0.0085	0.00088	9.67
	2000	0.0161	0.00184	8.75
	3000	0.0227	0.00291	7.80

[a]Based on effective gage length.

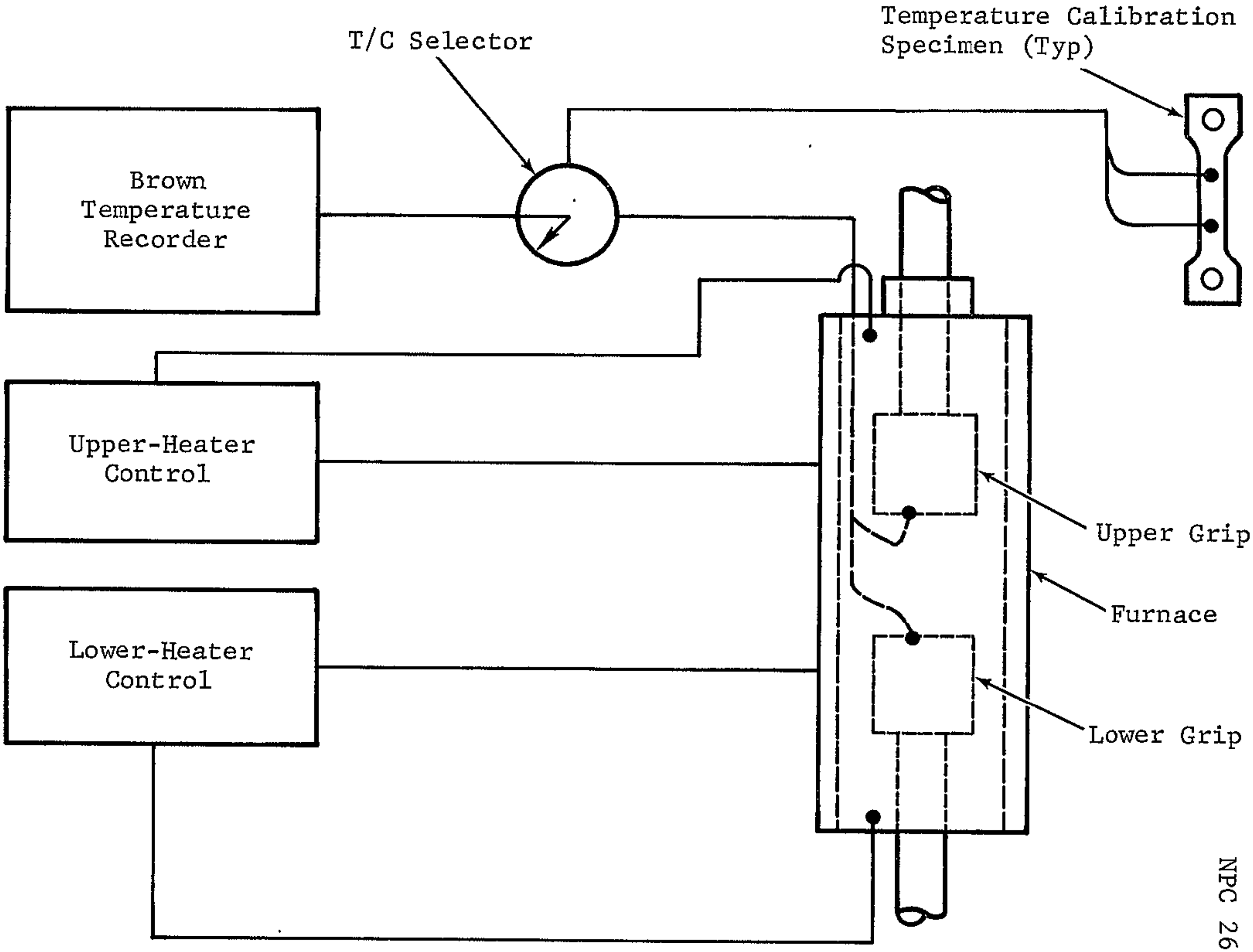


Figure 5-10 Schematic of Furnace Control System for the Instron Tester

NPC 26,832

7. The calibration was periodically checked by use of the thermocouple-instrumented specimen.

In addition to the furnace calibration, a test was performed to determine if the temperature of the specimen was uniform throughout its gage-length section and whether the application of load to the specimen would affect the specimen temperature. The procedure was as follows:

1. Two thermocouples were resistance-welded to the gage section of a specimen. One thermocouple was attached at the center of the gage and the other approximately 3/4 in. from the center.

2. With the furnace controller set to maintain the desired test temperature, the specimen was placed in the grips and brought to temperature. The temperature was allowed to stabilize and the readings of the two specimen thermocouples were recorded.

3. When at temperature equilibrium, a load of 2000 lb was applied to the specimen in 500-lb increments. The specimen temperatures were recorded at each step.

4. After cooldown, the specimen was inverted in the grips and Steps 2 and 3 were repeated.

From these tests it was determined that the temperature difference along the gage length of the specimen did not exceed $2^{\circ}F$. The application of load to the specimen produced no noticeable change in its temperature.

During the actual tensile testing, specimen temperatures were controlled to within $\pm 3^{\circ}F$ of the desired test temperature, as indicated by checks made with the thermocouple-instrumented specimen. In these checks, the temperature data were recorded for periods of time comparable to that required for the specimen tests in order to observe the time variation of the temperature.

5.3.3 Calibration of the Stress-Rupture Equipment

Creep-Measuring Equipment. Since the extensometer normally used to measure creep could not be attached directly to the specimen, a linkage system was devised to use the extensometer to measure displacement of the upper pull rod relative to the lower pull rod. This arrangement required the assumption that negligible strain occurs outside the reduced section of the specimen. Data to validate this assumption were obtained during the axiality tests and from bench measurements of the specimens made before and after testing.

Calibration of the extensometer systems of both testers was accomplished by mounting the extensometer in a micrometer-equipped calibration fixture and recording the indicated displacement at several displacements in the range of the extensometer. Figure 5-11 is a calibration curve for the extensometer system of both testers. This procedure was repeated periodically throughout the test program to ensure that the system was operating properly.

Axiality Checks. Axiality checks were conducted on each Riehle tester to ensure against misalignment of the pull rods and grips. The method was basically the same as that used in the axiality tests conducted on the Instron testers; the same test specimen, extensometer, and readout equipment were used. The main

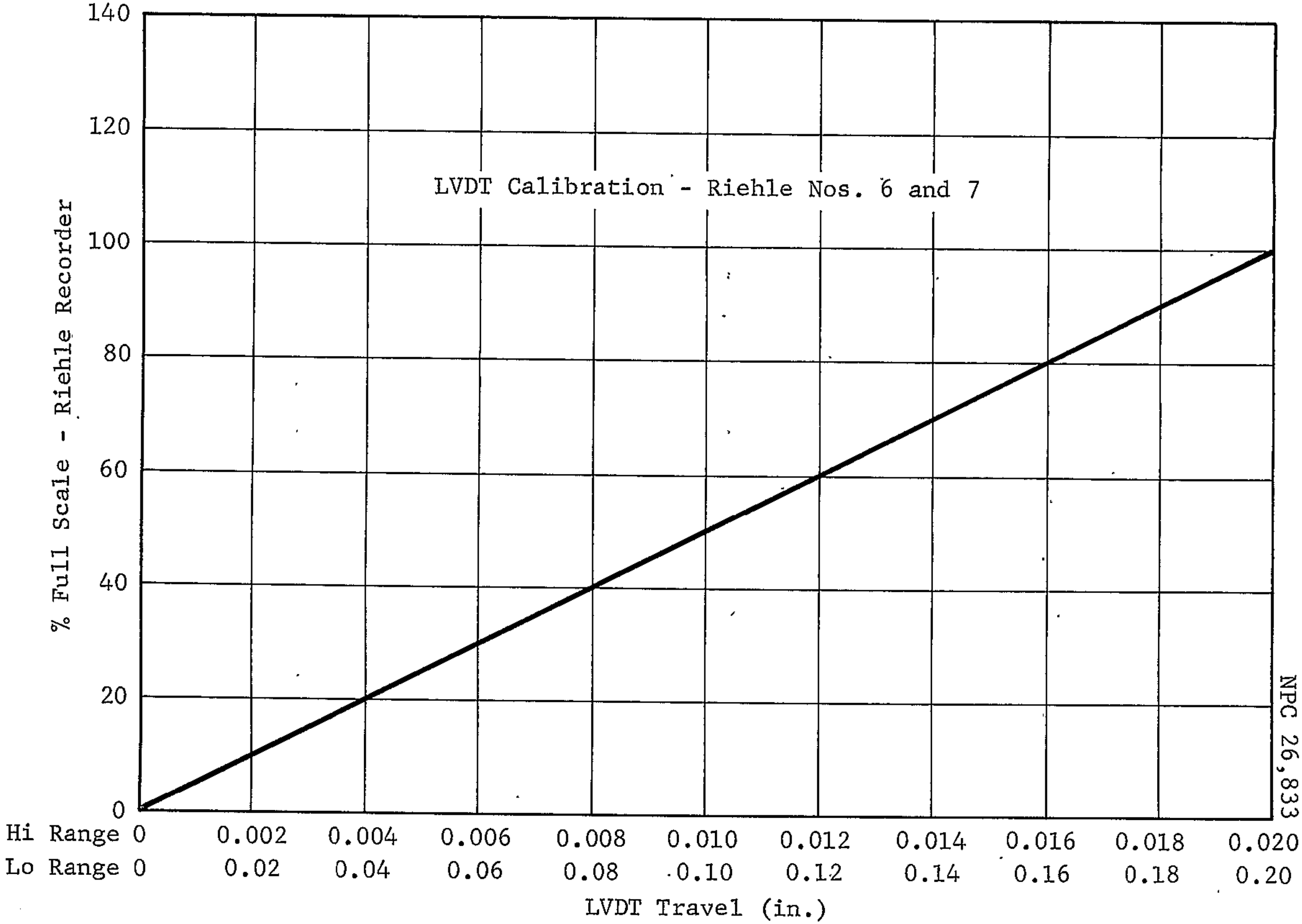


Figure 5-11 Calibration Curve of Riehle Extensometer System

NPC 26,833

difference was in the method of applying load to the specimen. The following procedure was followed in conducting the axiality tests:

1. The axiality specimen was installed in the grips and a load of 500 lb (15.9 ksi) was applied.

2. The extensometer was installed on the test specimen.

3. The load on the specimen was increased to 3000 lb (955 ksi) in 500-lb increments. Specimen elongation was measured and recorded at each point.

4. The load on the specimen was then reduced to 500 lb and the extensometer rotated 90 deg on the specimen; the loading sequence was then repeated. Measurements were also made at 180 and 270 deg from the initial position.

The elongations of the specimen at each position were then compared. The data given in Table 5-7 show the elongation for each of the four positions at 3000 lb to be within 5% of the average of the four.

During these tests, data were taken to correlate the upper-grip travel with the travel of the upper pull rod as indicated by the extensometer system. This was accomplished by mounting a dial indicator so as to measure the movement of the upper grip; this measurement was then compared with the indicated movement of the upper pull rod as the load was being applied to the specimen. The readings of the extensometer attached to the specimen were also compared with the upper-grip travel. Figure 5-12 is a schematic of the test setup showing the position of the dial indicators and extensometers.

Table 5-7

AXIALITY DATA FOR RIEHLE TESTERS

Tester/ Grips	Date	Specimen Load (lb)	Sanborn Scale Division Reading[a] 0°	90°	180°	270°	Avg	Max Dev	Maximum Deviation (%)	Avg Elong (in./in.)	Avg LVDT Travel (in.)	Avg Upper Grip Travel (in.)
Riehle #7/ Molybdenum Grips[b] S/N 15 & 16	3/13/68	500	0	0	0	0	-	-	-			
		1000	8.0	8.0	9.0	8.0	8.25	0.75	9.1	0.00052	0.0041	0.0034
		2000	24.5	26.5	22.5	24.0	24.38	2.12	8.7	0.00153	0.0131	0.0104
		3000	42.0	42.0	39.0	40.0	40.75	1.75	4.3	0.00255	0.0220	0.0173
Riehle #6/ René Grips S/N 13 & 14	3/15/68	500	0	0	0	0	0	-	-			
		1000	8.0	8.0	8.0	8.0	8.0	0	0	0.00050	0.0038	0.0040
		2000	25.0	25.0	26.0	26.0	25.5	0.5	2.0	0.00159	0.0146	0.0124
		3000	42.5	42.5	44.0	44.0	43.25	0.75	1.7	0.00260	0.0254	0.0198
Riehle #7/ René Grips S/N 11 & 12	4/10/68	500	0	0	0	0	-	-	-			
		1000	8.5	9.0	9.5	9.5	9.13	0.63	5.9	0.00057	0.0033	0.0042
		2000	28.0	27.2	28.0	27.0	27.55	0.55	2.0	0.00172	0.0107	0.0125
		3000	46.0	46.0	48.0	46.0	46.5	1.50	3.2	0.00291	0.0185	0.0195
Riehle #6/ René Grips S/N 13 & 14	5/16/68	500	0	0	0	0	-	-	-			
		1000	8.0	8.0	8.2	7.8	8.0	0.2	2.5	0.00050	0.0044	0.0048
		2000	24.0	24.0	25.5	23.0	24.1	1.4	5.8	0.00151	0.0136	0.0138
		3000	41.5	41.5	43.0	40.0	41.5	1.50	3.6	0.00259	0.0222	0.0225
Riehle #7/ René Grips S/N 11 & 12	5/28/68	500	0	0	0	0	-	-	-			
		1000	8.0	7.0	8.0	8.0	7.75	0.75	9.7	0.00048	0.0037	0.0050
		2000	24.5	23.0	25.0	24.5	24.25	1.25	5.2	0.00152	0.0127	0.0138
		3000	41.5	40.0	43.0	42.5	41.75	1.75	4.2	0.00261	0.0228	0.0221
Riehle #7/ René Grips S/N 11 & 12	6/11/68	500	0	0	0	0	-	-	-			
		1000	8.0	8.0	9.0	7.8	8.2	0.8	9.8	0.00051	-	-
		2000	24.0	24.0	26.0	23.5	24.37	1.63	6.7	0.00152	-	-
		3000	41.5	41.5	43.5	40.0	41.6	1.9	4.6	0.00260	-	-
Riehle #6/ René Grips S/N 13 & 14	6/11/68	1000	6.0	7.5	7.5	8.0	7.25	1.25	17.3	0.00045	-	-
		2000	22.0	23.5	23.5	24.5	23.37	1.37	5.9	0.00146	-	-
		3000	40.0	42.0	40.0	42.0	41.0	1.0	2.4	0.00256	-	-

[a]To convert Sanborn Scale Division Reading to inches of extension, multiply given value by 62.5 microinches per division.

[b]These grips were not used in the stress-rupture testing because of sublimation at the elevated temperatures.

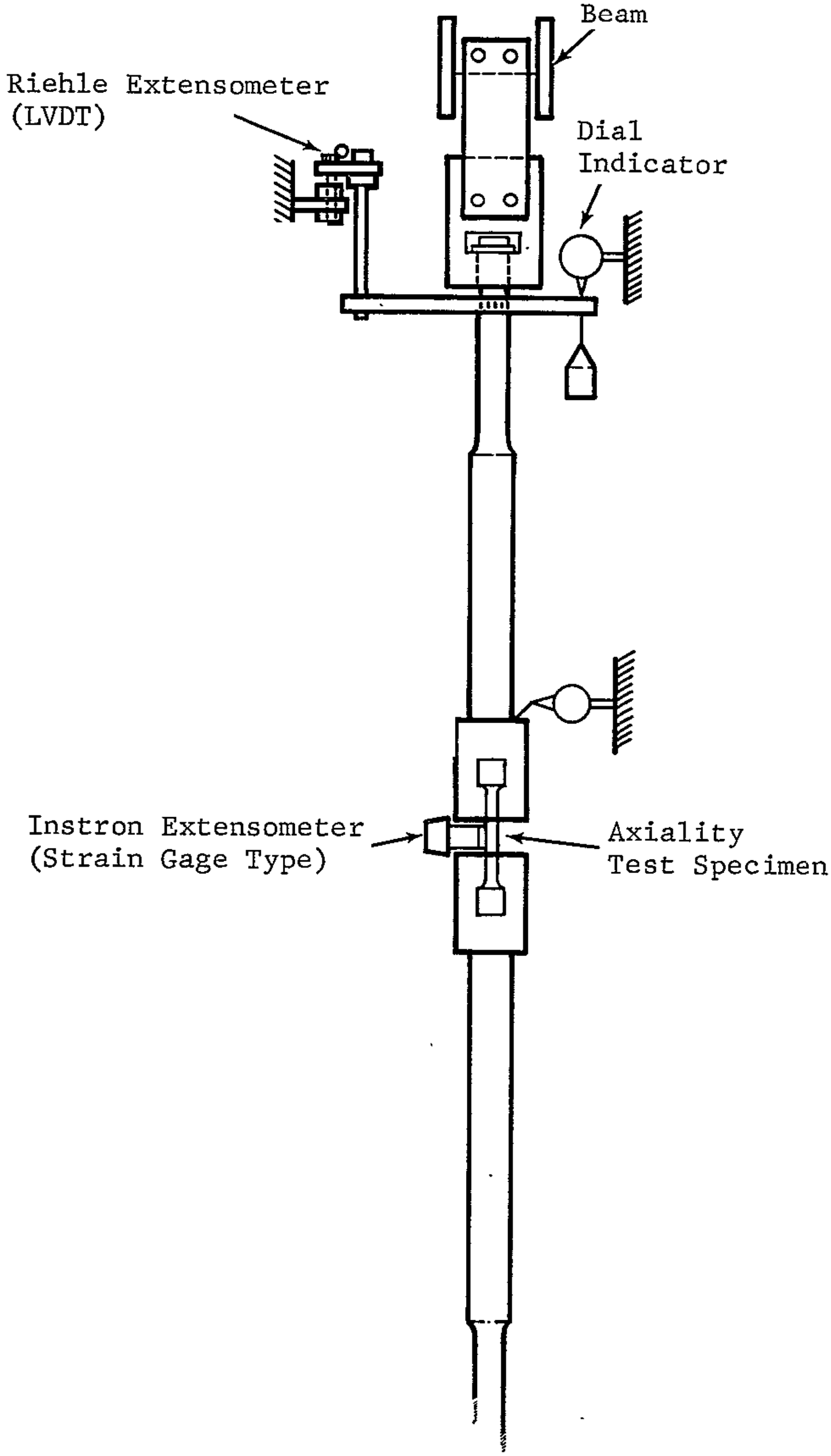


Figure 5-12 Schematic of Axiality Test Setup for Riehle Testers

It should be noted that with this arrangement, the movement of the upper pull rod and upper grip, as indicated by the LVDT and dial indicator during the application of weights, includes the deflection and slack in the lower ball-swivel assembly, pull rod and grip pins, and the specimen seating in the grips. Although the deflection and slack are significant, they do not have any influence on the indicated movement of the upper pull rod after the specimen has been loaded to the prescribed load of the actual test. The slack and deflection are a function of the change in load; therefore, it is assumed that once the specimen has been stabilized at test temperature and the prescribed load has been applied, any movement indicated by the LVDT attached to the upper pull rod will be due to elongation of the test specimen. Although there was some variation between the indicated LVDT travel and upper grip movement during loading of the specimen, it was demonstrated that after the specimen was loaded the two measurements were within 0.001 in. of each other when the complete assembly was moved by turning the positioning crank of the Riehle tester.

Furnace Calibration. Since the temperature of each test specimen could not be monitored directly, it was necessary to determine the temperatures required on the upper and lower grips (which were instrumented with thermocouples) in order to maintain the test specimens at the required temperature. A temperature correlation test was performed with an instrumented specimen installed in the grips; the temperatures of the furnace, grips, and the thermocoupled specimen were compared at the temperatures required for the test program. During the actual tests, the furnace and grips were maintained at the corresponding temperatures required to maintain the prescribed specimen temperature. Adjustment of the temperature distribution within the furnace was made by shunting across the external terminals of the furnace. An atmosphere of nitrogen was maintained in the furnace during all heating cycles.

5.3.4 Mechanical Properties Tests

Tensile Tests. All tensile tests were performed in the Irradiated Materials Laboratory using two Instron test machines. The test program was designed to evaluate the response characteristics of the test materials with neutron fluence, strain rate, and test temperature as variables. Control specimens were tested along with the irradiated specimens.

Specimens were installed in the grips and a slight load was applied to maintain alignment of the pull rods, grips, and specimen. The heater was positioned over the specimen and power was applied to the heater. A load of from 100 to 150 lb was maintained on the specimen to prevent slack from developing as a result of thermal expansion of the specimen, grips, and pull rods. Upon reaching equilibrium at the test temperature, the specimen was allowed to "soak" for 45 minutes before the test was started.

The Instron operator then maintained surveillance of the apparatus and the temperatures until completion of the test.

Stress-Rupture Tests. All stress-rupture tests were performed with the two Riehle testers. Each specimen was installed in the test grips and a slight load was applied to keep the grips in contact with the test specimen during the heating cycle. This load was 100 lb for the unnotched specimens and 40 lb for the combination-notched specimens. The furnace was then raised and gaseous nitrogen flow to the furnace was started. The furnace was closed and specimen heating was begun. Care was taken not to overshoot the required specimen temperature. Figure 5-13 is a typical temperature-vs-time plot showing the heating rate and stabilization period prior to loading the specimen. This particular curve was taken from the initial calibration of the heating equipment of Riehle No. 7. The variations in furnace thermocouple readings were due to adjustments in the control setting.

When the temperature had stabilized, the extensometer system was zeroed and the weights were applied to the tester pan. During the loading of the specimen, the deflection indications of the extensometer were monitored and recorded. After the required load was applied, the extensometer was rezeroed, the timer was set, and the starting time recorded. The test was monitored, periodically, until the specimen fractured. If at the end of the prescribed test time the specimen had not fractured, the tensile load on the

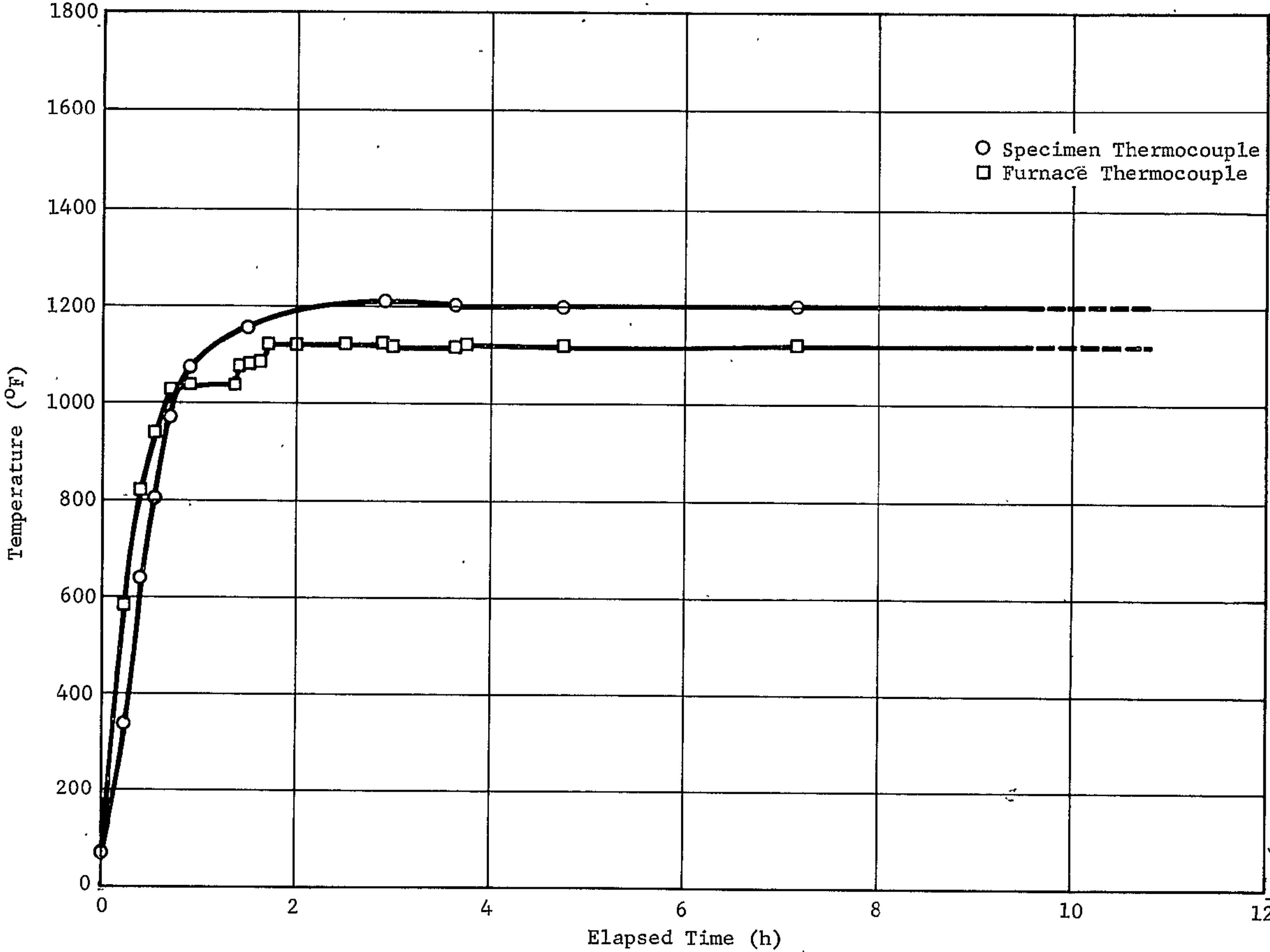


Figure 5-13 Typical Heating Rate of Stress-Rupture Specimens

NPC 26,835

specimen was increased by 5 ksi each hour until the specimen fractured. The prescribed test time for the unnotched specimens was 100 hours; test time for the combination-notched specimens was 23 hours.

VI. DISCUSSION AND PRESENTATION OF HIGH-TEMPERATURE TEST DATA

The tensile data for René 41, Waspaloy, and Inconel 718 are presented in Sections 6.2, 6.3, and 6.4, respectively. The stress-rupture data for Waspaloy and Inconel 718 are presented in Sections 6.5 and 6.6, respectively.

Each set of data is preceded by an index to the tables and figures in that section. In Section 6.1 information concerning the content of the tables and figures is presented, along with any additional information necessary to understand the data.

6.1 Discussion

The tensile data for the various test conditions were statistically compared by means of a t-test to determine if significant differences resulted. The t-test was not applied to the stress-rupture data; rather, these data were plotted as a function of neutron fluence to illustrate the effects of irradiation.

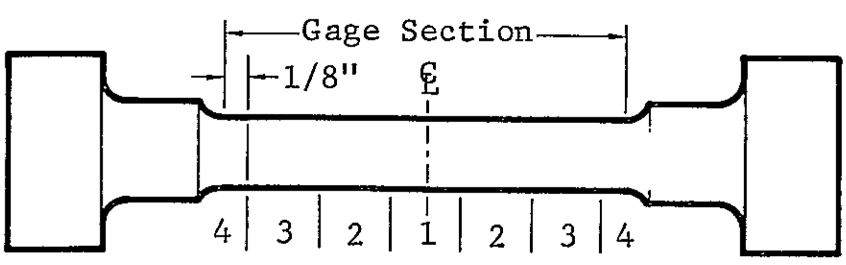
6.1.1 Tensile Data

The tensile test results are presented in two forms: data tables and stress-strain curves. The data tables are of two basic types - those containing tensile data on each individual specimen and those in which the effects of test conditions are compared.

6.1.1.1 Individual Specimen Data

The following general information and property data are presented in the data tables for René 41, Waspaloy, and Inconel 718:

1. Designation of the material
2. Specimen configuration and drawing number
3. Specimen number
4. Test condition (control or irradiated)
5. Average strain rate in the plastic region
6. Test temperature
7. Yield stress at 0.2% offset (S_y)
8. Maximum stress (S_m)
9. Fracture stress (S_f)
10. Percent elongation from both Instron chart and bench measurement
11. Percent area reduction from bench measurement
12. Fracture location specified as 1, 2, 3, or 4 corresponding to the sections indicated in the sketch. Sections 1, 2, and 3 were of an equal length that depended upon the elongation. T or O indicates that the break was, roughly, transverse or oblique, respectively.



13. Rockwell hardness (one specimen from each condition) before and after test

14. Radiation exposure in terms of gamma dose and fast- and thermal-neutron fluence (see Appendix A for the dosimetry procedures)

Some understanding of the stress and strain properties included in the above listing may be gained by referring to the stress-strain curve sketched on page 4-2.

In addition to the data for each individual specimen, the data tables give the average, standard deviation, and percent standard deviation for each group of specimens tested under the same conditions. Tables 6-1, 6-4, and 6-7 give the tensile data for René 41, Waspaloy, and Inconel 718, respectively.

Appendix B (Tables B-3, B-4, and B-5) contains supplementary data for each test specimen: the date of test, the gage-length diameter before and after test, and the gage length (plus shank) before and after test.

6.1.1.2 Statistical Comparisons

The statistical treatment of the data for the high-temperature materials is identical to that used for the cryogenic materials (Section 4.1.1.3). A t-test of significance was used to evaluate the observed difference between the average values when changing from one level of the test environment to another. These results are presented graphically as the difference between the averages, with a bar indicating the 90% confidence interval. Each comparison is made on both an absolute-value and percent-change basis.

The statistical comparisons are shown in Tables 6-2 and 6-3 for René 41, in Tables 6-5 and 6-6 for Waspaloy, and in Tables 6-8 and 6-9 for Inconel 718. Tables 6-10 and 6-11 indicate the effects of boron content on the properties of Inconel 718.

6.1.1.3 Stress-Strain Curves

Stress-strain curves are given for each tensile specimen. Curves for all specimens (usually three) for a given set of conditions have been computer-plotted on one graph. Each figure contains the following information:

1. Designation of the material
2. Specimen numbers and plotted symbols
3. Test conditions
4. Stress-strain curves (based on crosshead travel)
5. Strain-measuring device (Instron)
6. Minimum cross-sectional area of specimens
7. Gage length of the specimens (from the design drawing)
8. Radiation exposure (fast- and thermal-neutron fluences and gamma dose)
9. Date the irradiation was completed
10. Date (month and year) of tensile test

Accompanying each set of stress-strain curves is a set in which the curves have been fitted to the handbook modulus of elasticity. The procedure for developing these curves is described in Section 4.1.2. The moduli of elasticity, provided by AGC, are:

Material	Temp. (^{o}R)	Modulus (10^6 psi)
René 41	1660	26.0
	1860	25.0
Waspaloy	1560	26.0
	1660	25.5
	1860	24.0
Inconel 718	1360	25.3
	1510	24.0
	1660	23.0
	1760	22.7

The stress-strain-curve figures are presented as pairs - the first, or odd-numbered, figure being the curves based on Instron crosshead travel, and the second, or even-numbered, figure being the stress-strain curves based on the appropriate handbook modulus. The stress-strain curves for René 41 are given in Figures 6-1 through 6-18; for Waspaloy, in Figures 6-19 through 6-42; and for Inconel 718, in Figures 6-43 through 6-78.

Above the yield point, the recorder-plotted stress-strain curves for Inconel specimens N 02, N 03, N 36, N 37, N 39, N 41, N 42, and N 43 show a series of oscillations. These oscillations, which were accompanied by cracking sounds during the tensile testing, are a characteristic of this type of material under certain conditions. On the computer-plotted stress-strain curves, a double row of data points indicates the magnitude of these oscillations.

A minimum of scale changes have been made in the plotting in order to make the various sets of data more easily comparable.

The scales were selected to provide maximum utilization of plotting space consistent with easily divisible scales.

It should be noted that data points have not been plotted for the initial linear portion of the curves. Also, the terminology of "low," "medium," or "high" irradiation used in the figure titles denotes the exposure level as determined by the specimen location with respect to the reactor.

6.1.2 <u>Stress-Rupture Data</u>

The stress-rupture data are presented in data tables and as curves of total elongation and percent elongation as a function of test time.

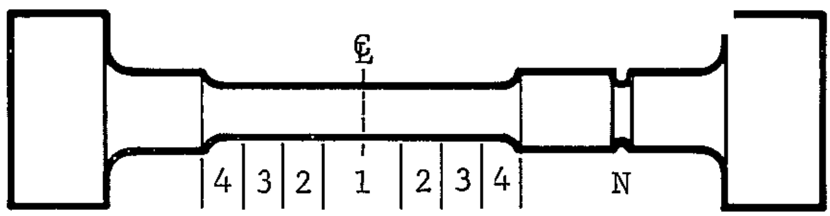
6.1.2.1 <u>Data Tables</u>

The following information and property data are presented in the data tables for Waspaloy and Inconel 718:

1. Designation of the material
2. Specimen configuration and drawing number
3. Specimen number (Note: NS or WS indicates combination-notched specimen)
4. Test condition (control or irradiated)
5. Test temperature
6. Stress, or range of stresses, to which specimen was loaded
7. Time to rupture
8. Percent elongation from both the Riehle chart and the bench measurements

9. Percent area reduction from bench measurements

10. Fracture location as indicated in the sketch by sections 1, 2, 3, or 4. N denotes fracture at the notch.



11. Date specimen fail

12. Radiation exposure in terms of gamma dose and fast- and thermal-neutron fluence (see Appendix A for dosimetry procedures)

Tables 6-12 and 6-13 contain the data for Waspaloy and Inconel 718, respectively. Appendix B (Tables B-4, B-5, and B-6) contains supplementary data for each test specimen: the gage-length diameter before and after testing and the gage length (plus shank) before and after testing.

6.1.2.2 Data Plots

The data for all Waspaloy and Inconel 718 specimens (except for those that fractured at the notch) are plotted as total extension and percent elongation vs test time in Figures 6-79 through 6-85 and 6-88 through 6-94. In each plot, the left-hand scale is extension as taken from the recorder charts; the right-hand scale is the total extension divided by the gage length. The gage lengths are taken to be 1.50 in. for the unnotched specimens and 0.978 in. for the combination-notched specimens. The final data point on each curve is at the time of specimen rupture. A tabulation of total extension at 5-hour (or shorter) intervals is given in Appendix D.

It will be observed that the curves for the unnotched Waspaloy specimens do not pass through zero. This is because the prescribed load for this material was slightly higher than the yield point at 1660°R, and this initial extension took place as the last weights were added to the pan. The offset represents the extension which took place during the loading of the specimen.

6.1.2.3 Analysis

The t-tests of significance were not applied to the stress-rupture data. Several of the control specimens did not break within the prescribed time limit and were loaded to higher stresses; they were thus subjected to different test conditions than the specimens which broke in less than the prescribed time limit. Furthermore, the dispersion in the time-to-rupture data suggests a non-normal distribution for which the t-test would be inappropriate.

However, the fact that significant changes in properties occurred in the irradiated specimens is apparent from the data presented in Figures 6-86 and 6-87 for Waspaloy and Figures 6-95 and 6-96 for Inconel 718, which show time to failure, percent elongation (chart and bench), and percent area reduction plotted as a function of the logarithm of the neutron fluence. The dashed lines connecting the data points in these figures are intended to indicate trends in the data and do not represent the actual functional relationship between the measured property and the neutron fluence.

Section 6.2

Presentation of
René 41 Tensile Data

INDEX TO RENÉ 41 TENSILE DATA

Condition	Test Temp (°R)	Spec. No.	Instron Data Table	Instron Data Page	Stat. Comparisons Abs. Value Table	Stat. Comparisons Abs. Value Page	Stat. Comparisons % Change Table	Stat. Comparisons % Change Page	Stress-Strain Curves Measured Fig.	Stress-Strain Curves Measured Page	Stress-Strain Curves Fitted Fig.	Stress-Strain Curves Fitted Page
Contr	1660	R1 01 R1 02[a] R1 03 R2 07	6-1	6-14	6-2	6-16 6-17	6-3	6-18 6-19	6-1	6-20	6-2	6-21
Low Irrad	1660	R1 04 R1 05 R1 06							6-3	6-22	6-4	6-23
Med Irrad	1660	R1 13 R1 14 R1 15							6-5	6-24	6-6	6-25
High Irrad	1660	R1 16 R1 17 R1 18							6-7	6-26	6-8	6-27
High Irrad[b]	1660	R2 22 R2 23 R2 24		6-15					6-9 6-11	6-28 6-30	6-10 6-12	6-29 6-31
Contr	1860	R2 08 R2 09 R2 26							6-13	6-32	6-14	6-33
Low Irrad	1860	R2 10 R2 11 R2 12							6-15	6-34	6-16	6-35
Med Irrad	1860	R2 19 R2 20 R2 21							6-17	6-36	6-18	6-37

[a]Broke on loading

[b]Different strain rate

PRECEDING PAGE BLANK NOT FILMED

Table 6-1

TENSILE TEST DATA FOR INDIVIDUAL SPECIMENS OF RENÉ 41

Specimen configuration: round-unnotched - Dwg. No. AGC 1134298-1. Data to be used for material evaluation only. Do not use for design.

Specimen Number	Condition	Strain Rate (in./in./min)	Test Temp (°R)	0.2% Offset Yield Stress (ksi)	Max Stress (ksi)	Frac Stress (ksi)	% Elongation		% Area Reduct (Bench)	Frac Location	Hardness, Rockwell C		Radiation Exposure		
							Bench	Chart			Pre-Test	Post-Test	Gamma Dose [ergs/g(C)]	Neutron Fluence (n/cm²) E > 1 MeV	E < 0.48 eV
R1 01	Control	0.0013	1660	112.88	157.09	156.77	9.86	9.44	13.13	(3) T					
R1 02				Broke on Loading											
R1 03				112.76	161.08	161.08	11.06	10.48	14.80	(1) T					
R2 07				117.14	164.25	163.93	10.59	10.53	13.53	(2) T	39.7	38.8			
Average				114.26	160.81	160.59	10.50	10.15	13.82						
Std Dev				2.49	3.59	3.60	0.60	0.62	0.87						
% Std Dev				2.18	2.23	2.24	5.76	6.06	6.31						
R1 04	Irrad	0.0013	1660	112.14	140.08	140.08	6.59	5.58	14.62	(2) T			2.3(11)	4.90(15)	8.60(15)
R1 05				117.63	157.57	157.57	5.14	6.50	12.49	(2) T			2.3(11)	5.00(15)	8.80(15)
R1 06				114.91	143.24	143.24	7.25	5.43	16.75	(1) T	37.7	37.1	2.4(11)	5.10(15)	9.00(15)
Average				114.89	146.96	146.96	6.33	5.84	14.62						
Std Dev				2.75	9.32	9.32	1.08	0.58	2.13						
% Std Dev				2.39	6.34	6.34	17.1	9.93	14.6						
R1 13	Irrad	0.0013	1660	117.86	144.55	142.96	5.83	4.29	6.57	(1) T	38.7	35.5	9.0(11)	8.20(16)	2.10(17)
R1 14				114.98	145.28	145.28	5.62	4.32	13.81	(2) O			8.8(11)	7.80(16)	2.00(17)
R1 15				112.89	136.42	135.15	4.92	3.87	9.83	(3) T			8.6(11)	7.40(16)	1.89(17)
Average				115.24	142.08	141.13	5.46	4.16	10.07						
Std Dev				2.50	4.92	5.31	0.48	0.25	3.63						
% Std Dev				2.17	3.46	3.76	8.73	6.05	36.0						
R1 16	Irrad	0.0013	1660	115.49	134.48	130.68	4.83	3.46	11.70	(2) T			3.0(12)	1.03(18)	4.41(18)
R1 17				116.79	143.13	140.27	4.35	3.91	6.68	(3) O	38.9	37.0	3.0(12)	1.06(18)	4.51(18)
R1 18				115.19	136.7	136.7	4.92	3.40	11.08	(3) T			3.0(12)	1.04(18)	4.40(18)
Average				115.82	138.10	135.88	4.70	3.59	9.82						
Std Dev				0.85	4.49	4.85	0.31	0.28	2.74						
% Std Dev				0.73	3.26	3.57	6.52	7.76	27.9						

Strain values are based on Instron crosshead travel, not extensometer measurements.
Strain rates are average values for the plastic region based on crosshead speed and a 1.50-in. gage length.

Table 6-1 (Cont'd)

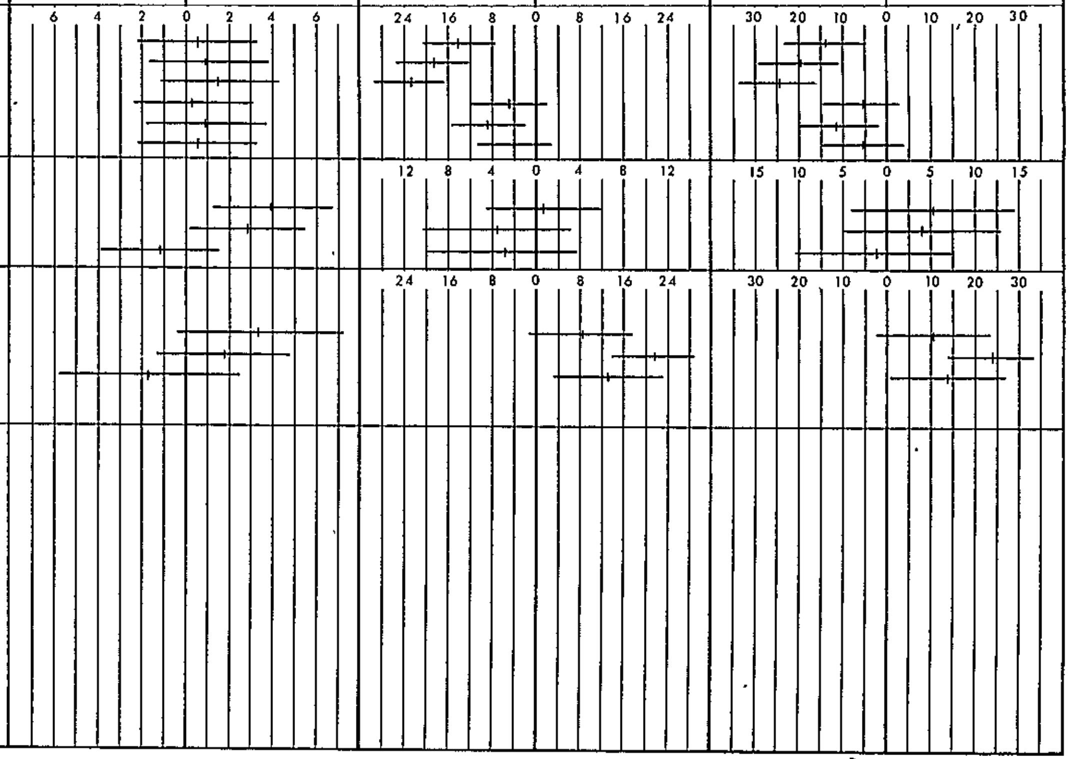
Specimen Number	Condition	Strain Rate (in./in./min)	Test Temp (°R)	0.2% Offset Yield Stress (ksi)	Max Stress (ksi)	Frac Stress (ksi)	% Elongation		% Area Reduct (Bench)	Frac Location	Hardness, Rockwell C		Radiation Exposure		
													Gamma Dose [ergs/g(C)]	Neutron Fluence (n/cm^2)	
							Bench	Chart			Pre-Test	Post-Test		E > 1 MeV	E < 0.48 eV
R2 22[a]	Irrad	0.013	1660	119.24	146.54	146.39	8.19	3.64	17.88	(1) T	38.6	38.9	2.9(12)	1.02(18)	4.29(18)
R2 23		0.13		116.97	159.00	159.00	12.07	11.62	15.50	(4) T			2.9(12)	9.80(17)	4.10(18)
R2 24		0.13		118.20	160.60	160.60	11.98	11.20	18.28	(2) T	38.6	38.2	2.8(12)	9.35(17)	3.90(18)
Average				117.59	159.80	159.80	12.03	11.41	16.89						
Std Dev				0.87	1.13	1.13	0.06	0.30	1.97						
% Std Dev				0.74	0.71	0.71	0.53	2.60	11.6						
R2 08	Control	0.0013	1860	112.40	120.75	114.00	3.47	3.01	9.19	(3) T					
R2 09				112.10	120.63	104.21	6.39	6.39	10.93	(1) T					
R2 26				111.93	119.2	103.35	5.61	5.76	8.41	(1) T	39.2	38.1			
Average				112.14	120.19	107.19	5.16	5.05	9.51						
Std Dev				0.24	0.86	5.92	1.51	1.80	1.29						
% Std Dev				0.21	0.71	5.52	29.3	35.6	13.6						
R2 10	Irrad	0.0013	1860	117.49	121.32	118.13	1.92	0.80	3.70	(1) T	38.2	37.2	2.4(11)	5.20(15)	9.20(15)
R2 11				113.73	115.32	101.66	1.87	3.03	4.16	(1) T			2.5(11)	5.30(15)	9.20(15)
R2 12				117.07	121.67	117.54	2.03	1.12	8.96	(1) T			2.4(11)	5.20(15)	9.00(15)
Average				116.10	119.44	112.44	1.94	1.65	5.61						
Std Dev				2.06	3.57	9.34	0.08	1.21	2.91						
% Std Dev				1.77	2.99	8.31	4.22	73.1	52.0						
R2 19	Irrad	0.0013	1860	114.23	114.54	107.06	2.09	1.63	4.84	(2) T	39.3	37.9	8.4(11)	7.00(16)	1.78(17)
R2 20				114.05	117.99	111.68	1.49	0.700	4.83	(1) T			8.1(11)	6.50(16)	1.66(17)
R2 21				116.58	117.53	114.82	1.62	0.687	9.57	(1) T			7.8(11)	6.10(16)	1.51(17)
Average				114.95	116.69	111.19	1.73	1.01	6.41						
Std Dev				1.41	1.87	3.90	0.32	0.54	2.73						
% Std Dev				1.23	1.61	3.51	18.2	53.8	42.6						

[a] Not included in average

Table 6-2

FECT OF TEST CONDITIONS ON THE TENSILE PROPERTIES OF RENÉ 41 -
COMPARISON ON AN ABSOLUTE-VALUE BASIS

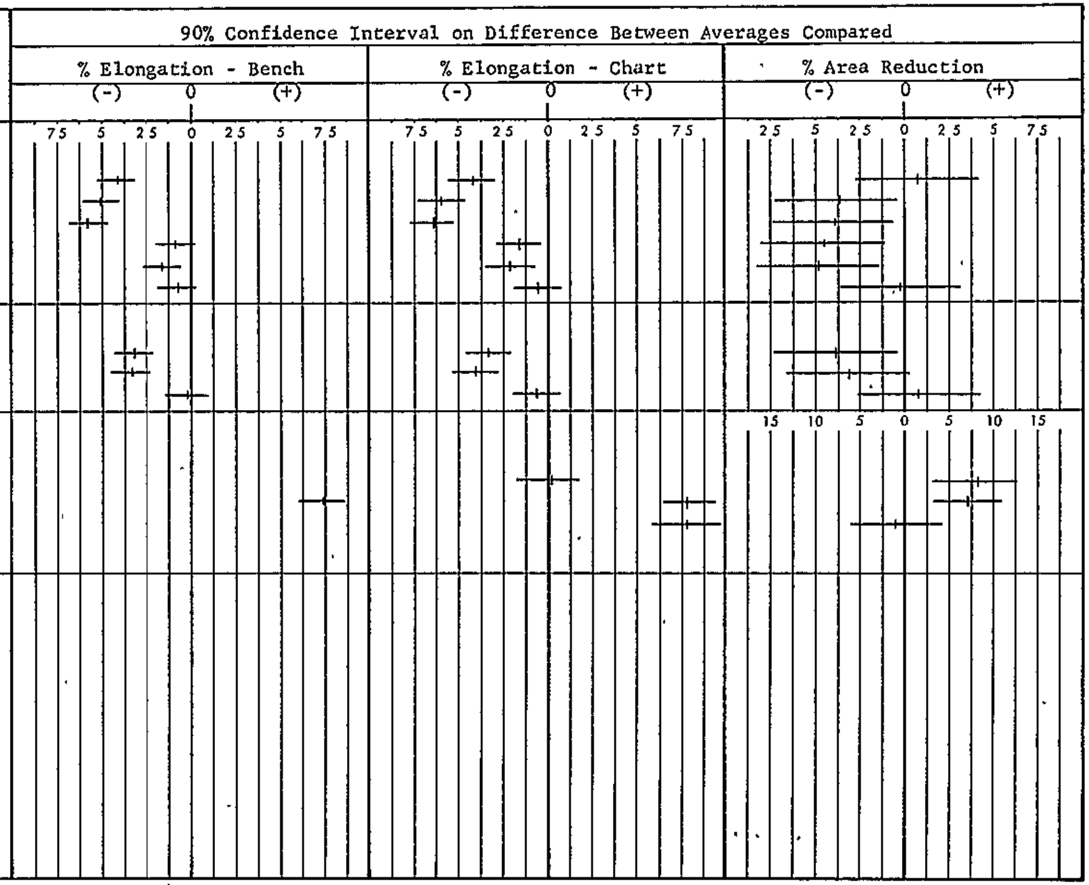
Test Temp. (°R)	Strain Rate (in./in./min)	Specimen Data Compared[a]	90% Confidence Interval on Difference Between Averages Compared: 0.2% Offset Yield Stress (ksi) (-) 0 (+); Maximum Stress (ksi) (-) 0 (+); Fracture Stress (ksi) (-) 0 (+)
1660	0.0013	Control vs low irrad Control vs med irrad Control vs high irrad Low irrad vs med irrad Low irrad vs high irrad Med irrad vs high irrad	
1860	0.0013	Control vs low irrad Control vs med irrad Low irrad vs med irrad	
1660	As compared	High irradiation 0.0013 vs 0.013 in./in./min 0.0013 vs 0.13 in./in./min 0.013 vs 0.13 in./in./min	



[a]Comparison is always second condition compared to the first condition.

Table 6-2 (Cont'd)

Test Temp. (°R)	Strain Rate (in./in./min)	Specimen Data Compared[a]
1660	0.0013	Control vs low irrad Control vs med irrad Control vs high irrad Low irrad vs med irrad Low irrad vs high irrad Med irrad vs high irrad
1860	0.0013	Control vs low irrad Control vs med irrad Low irrad vs med irrad
1660	As compared	High irradiation 0.0013 vs 0.013 in./in./min 0.0013 vs 0.13 in./in./min 0.013 vs 0.13 in./in./min

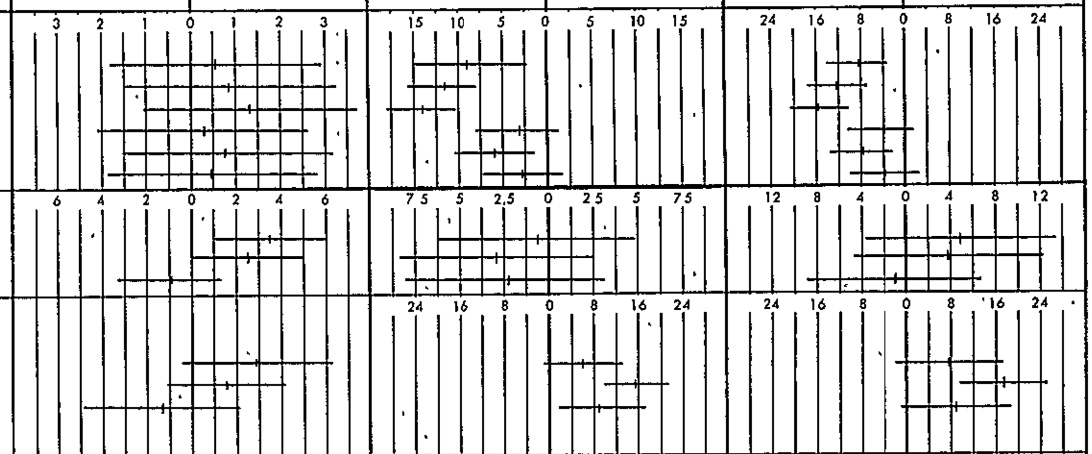


[a]Comparison is always second condition compared to the first condition.

Table 6-3

EFFECT OF CONDITIONS ON THE TENSILE PROPERTIES OF RENÉ 41 -
COMPARISON ON A PERCENT-CHANGE BASIS

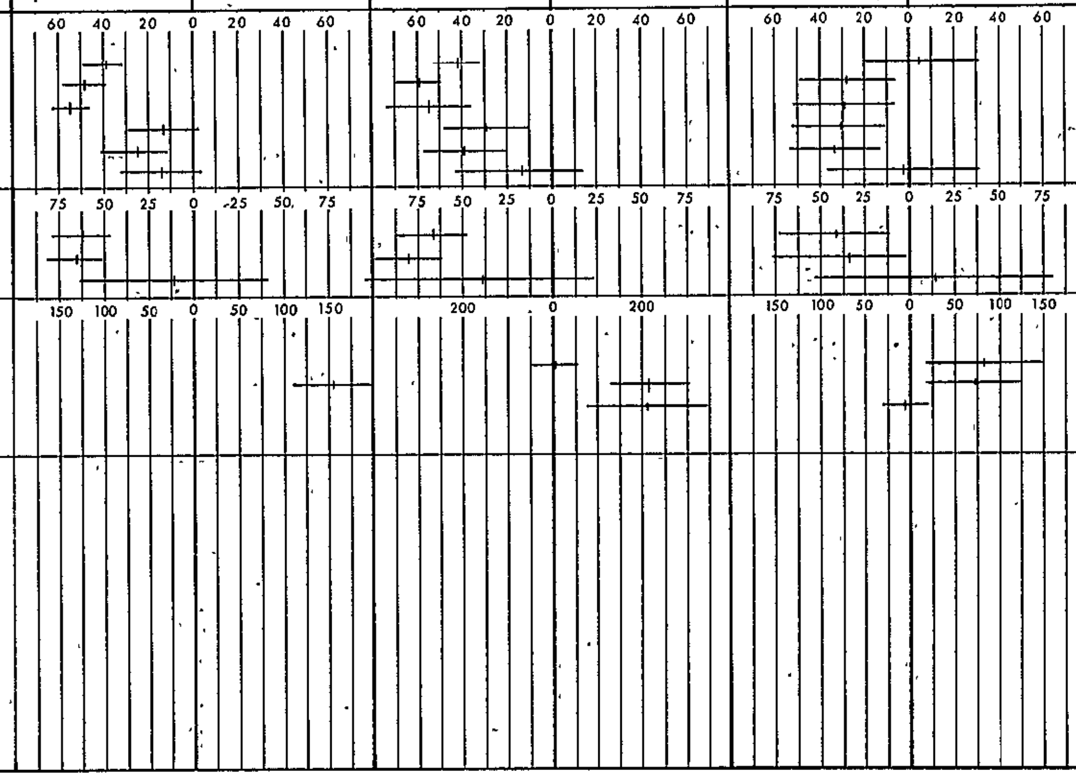
Test Temp. (°R)	Strain Rate (in./in./min)	Specimen Data Compared[a]	90% Confidence Interval on Difference Between Averages Compared: 0.2% Offset Yield Stress (-) 0 (+)	Maximum Stress (-) 0 (+)	Fracture Stress (-) 0 (+)
1660	0.0013	Control vs low irrad Control vs med irrad Control vs high irrad Low irrad vs med irrad Low irrad vs high irrad Med irrad vs high irrad	3 2 1 0 1 2 3	15 10 5 0 5 10 15	24 16 8 0 8 16 24
1860	0.0013	Control vs low irrad Control vs med irrad Low irrad vs med irrad	6 4 2 0 2 4 6	7.5 5 2.5 0 2.5 5 7.5	12 8 4 0 4 8 12
1660	As compared	High irradiation 0.0013 vs 0.013 in./in./min 0.0013 vs 0.13 in./in./min 0.013 vs 0.13 in./in./min		24 16 8 0 8 16 24	24 16 8 0 8 16 24



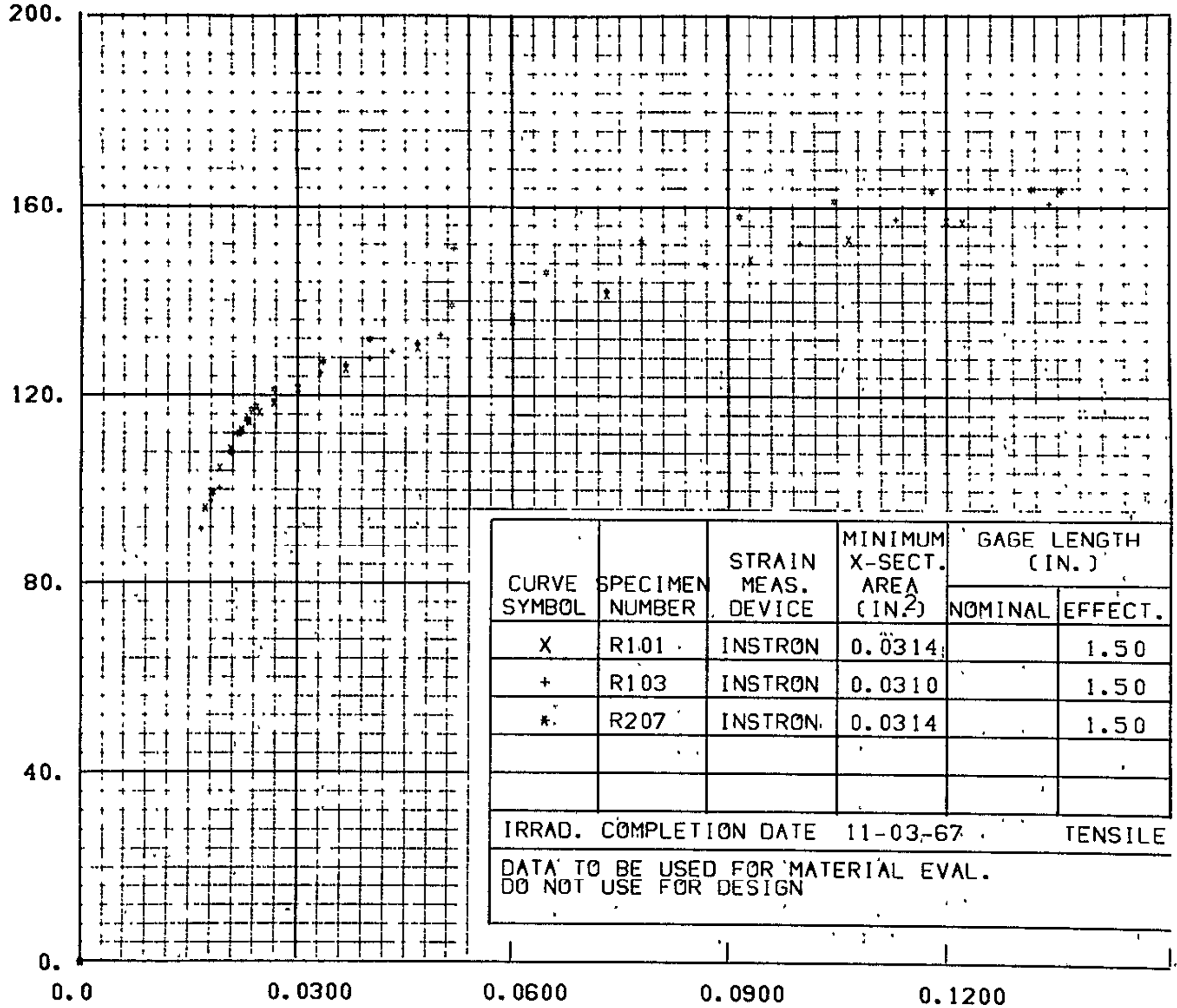
[a]Comparison is always second condition compared to the first condition.

Table 6-3 (Cont'd)

Test Temp. (^oR)	Strain Rate (in./in./min)	Specimen Data Compared[a]	90% Confidence Interval on Difference Between Averages Compared: % Elongation - Bench (-) 0 (+)	% Elongation - Chart (-) 0 (+)	% Area Reduction (-) 0 (+)
1660	0.0013	Control vs low irrad Control vs med irrad Control vs high irrad Low irrad vs med irrad Low irrad vs high irrad Med irrad vs high irrad	60 40 20 0 20 40 60	60 40 20 0 20 40 60	60 40 20 0 20 40 60
1860	0.0013	Control vs low irrad Control vs med irrad Low irrad vs med irrad	75 50 25 0 25 50 75	75 50 25 0 25 50 75	75 50 25 0 25 50 75
1660	As compared	High irradiation 0.0013 vs 0.013 in./in./min 0.0013 vs 0.13 in./in./min 0.013 vs 0.13 in./in./min	150 100 50 0 50 100 150	200 0 200	150 100 50 0 50 100 150



[a]Comparison is always second condition compared to the first condition.



CURVE SYMBOL	SPECIMEN NUMBER	STRAIN MEAS. DEVICE	MINIMUM X-SECT. AREA (IN.^{2})	GAGE LENGTH (IN.) NOMINAL	GAGE LENGTH (IN.) EFFECT.	FLUENCE (NEUTRONS/CM^2) THERMAL	FLUENCE (NEUTRONS/CM^2) FAST	GAMMA DOSE (ERGS/GM(C))
X	R101	INSTRON	0.0314		1.50	CONT		
+	R103	INSTRON	0.0310		1.50	CONT		
*	R207	INSTRON	0.0314		1.50	CONT		

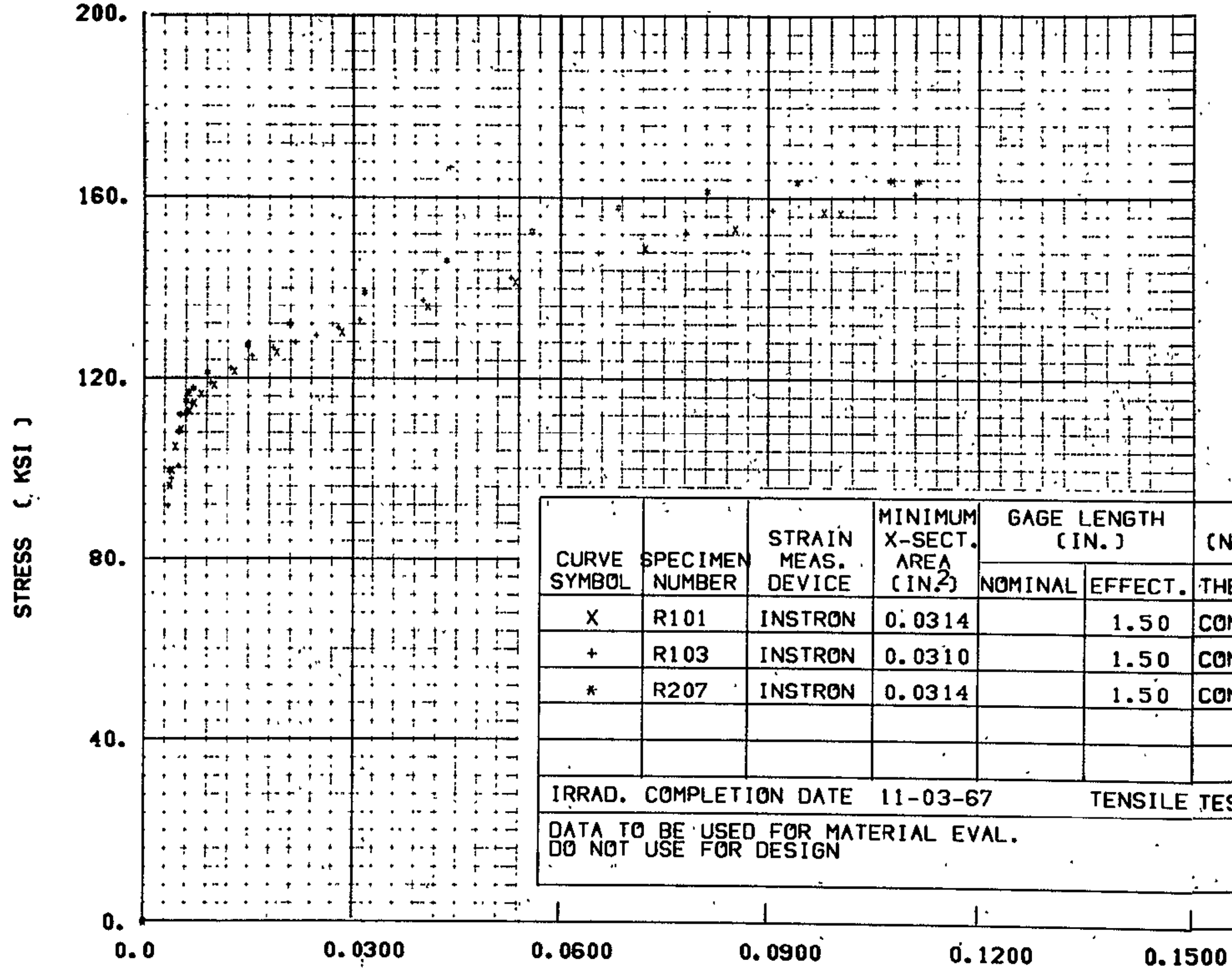
IRRAD. COMPLETION DATE 11-03-67 TENSILE TEST DATE MAR. 68

DATA TO BE USED FOR MATERIAL EVAL.
DO NOT USE FOR DESIGN

STRAIN (IN./IN. OF GAGE LENGTH)(BASED ON CROSSHEAD TRAVEL)

FIGURE 6-1 STRESS-STRAIN CURVES FOR RENE 41. CONTROLS TESTED AT 1660 R (0.0013 IN./IN./MIN).

NPC 26,910



CURVE SYMBOL	SPECIMEN NUMBER	STRAIN MEAS. DEVICE	MINIMUM X-SECT. AREA (IN.^{2})	GAGE LENGTH (IN.) NOMINAL	GAGE LENGTH (IN.) EFFECT.	FLUENCE (NEUTRONS/CM^2) THERMAL	FLUENCE (NEUTRONS/CM^2) FAST	GAMMA DOSE (ERGS/GM(C))
X	R101	INSTRON	0.0314		1.50	CONT		
+	R103	INSTRON	0.0310		1.50	CONT		
*	R207	INSTRON	0.0314		1.50	CONT		

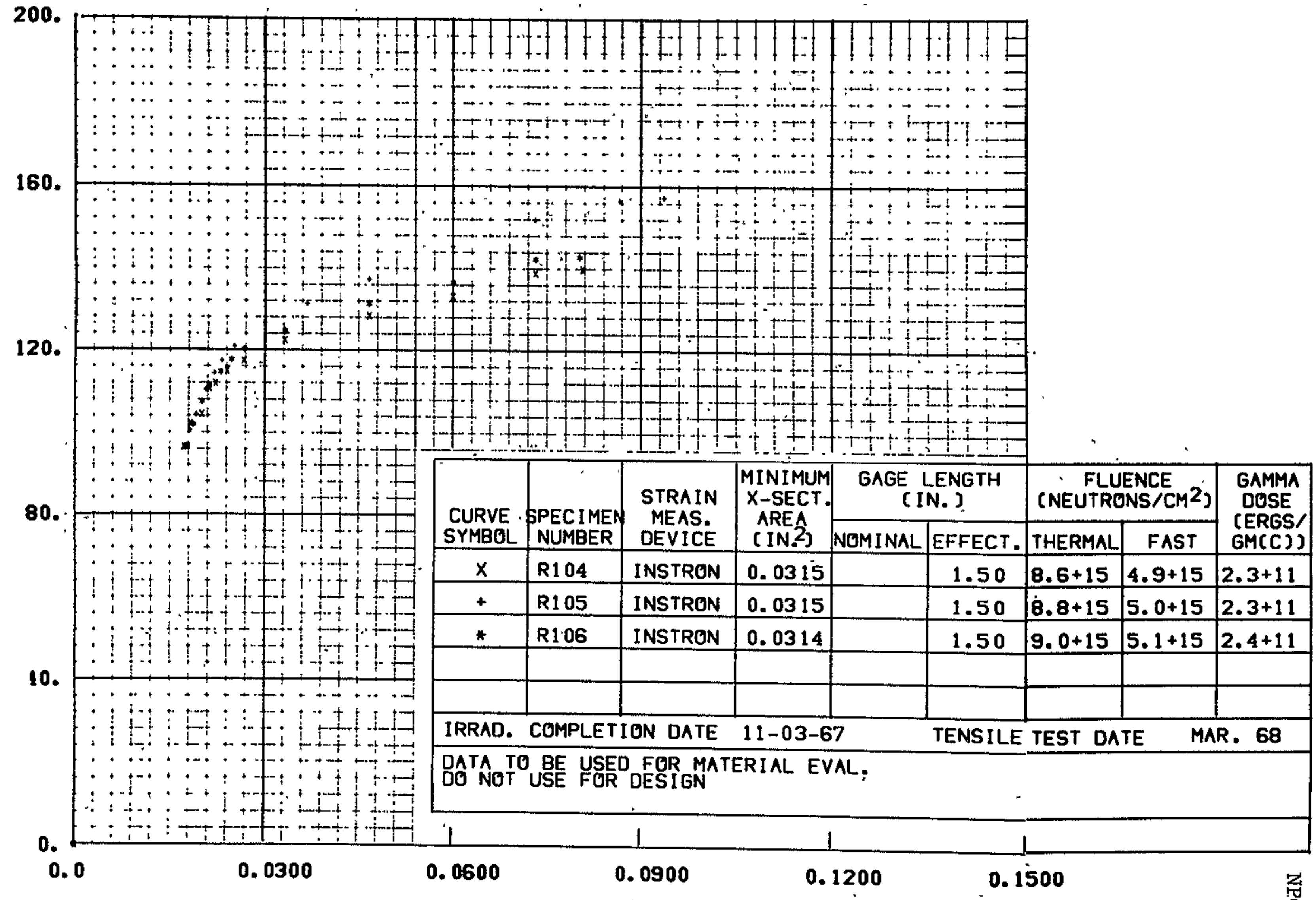
IRRAD. COMPLETION DATE 11-03-67 TENSILE TEST DATE MAR. 68

DATA TO BE USED FOR MATERIAL EVAL.
DO NOT USE FOR DESIGN

STRAIN (IN./IN. OF GAGE LENGTH)(BASED ON HANDBOOK MODULUS)

FIGURE 6-2 STRESS-STRAIN CURVES FOR RENE 41. CONTROLS TESTED AT 1660 R (0.0013 IN./IN./MIN). FITTED TO HDBK MOD

NPC 26,911

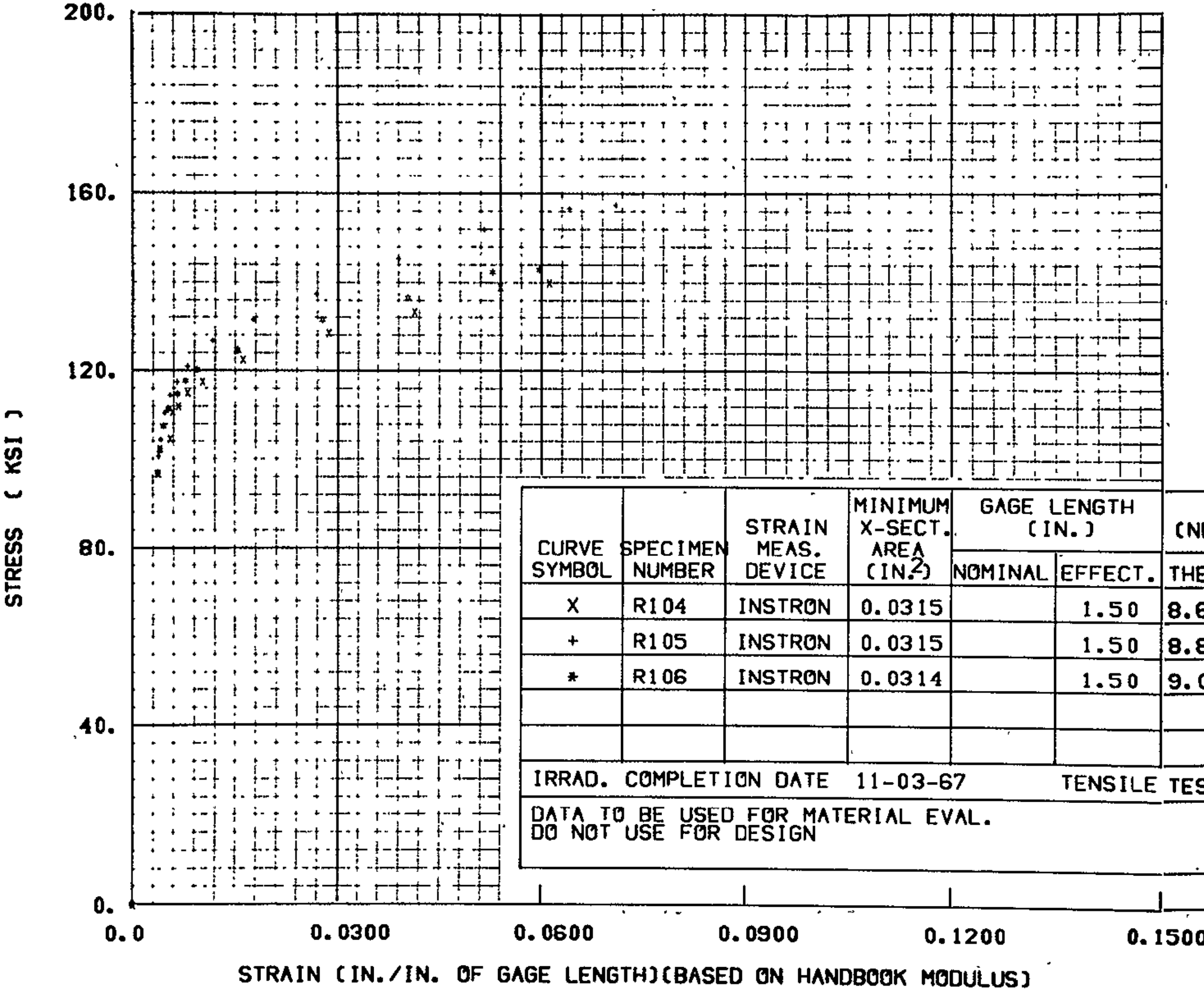


CURVE SYMBOL	SPECIMEN NUMBER	STRAIN MEAS. DEVICE	MINIMUM X-SECT. AREA (IN.^{2})	GAGE LENGTH (IN.)		FLUENCE (NEUTRONS/CM^2)		GAMMA DOSE (ERGS/GM(C))
				NOMINAL	EFFECT.	THERMAL	FAST	
X	R104	INSTRON	0.0315		1.50	8.6+15	4.9+15	2.3+11
+	R105	INSTRON	0.0315		1.50	8.8+15	5.0+15	2.3+11
*	R106	INSTRON	0.0314		1.50	9.0+15	5.1+15	2.4+11

IRRAD. COMPLETION DATE 11-03-67 TENSILE TEST DATE MAR. 68

DATA TO BE USED FOR MATERIAL EVAL.
DO NOT USE FOR DESIGN

FIGURE 6-3 STRESS-STRAIN CURVES FOR RENE 41. LOW IRRAD
TESTED AT 1660 R (0.0013 IN./IN./MIN).



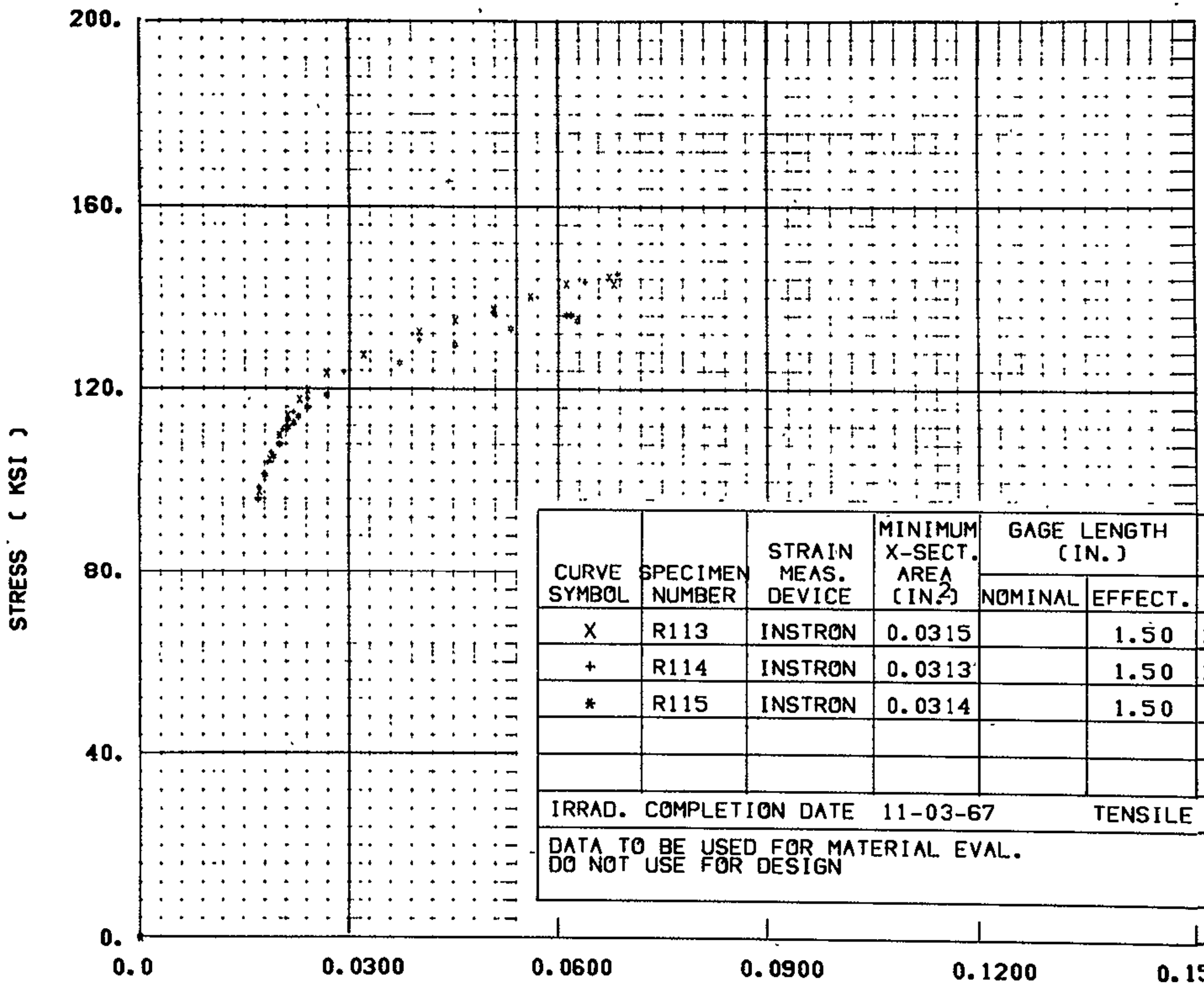
CURVE SYMBOL	SPECIMEN NUMBER	STRAIN MEAS. DEVICE	MINIMUM X-SECT. AREA (IN.^{2})	GAGE LENGTH (IN.) NOMINAL	GAGE LENGTH (IN.) EFFECT.	FLUENCE (NEUTRONS/CM^2) THERMAL	FLUENCE (NEUTRONS/CM^2) FAST	GAMMA DOSE (ERGS/GM(C))
X	R104	INSTRON	0.0315		1.50	8.6+15	4.9+15	2.3+11
+	R105	INSTRON	0.0315		1.50	8.8+15	5.0+15	2.3+11
*	R106	INSTRON	0.0314		1.50	9.0+15	5.1+15	2.4+11

IRRAD. COMPLETION DATE 11-03-67 TENSILE TEST DATE MAR. 68

DATA TO BE USED FOR MATERIAL EVAL.
DO NOT USE FOR DESIGN

FIGURE 6-4 STRESS-STRAIN CURVES FOR RENE 41. LOW IRRAD
TESTED AT 1660 R (0.0013 IN./IN./MIN). FITTED TO HDBK MOD

NPC 26,913



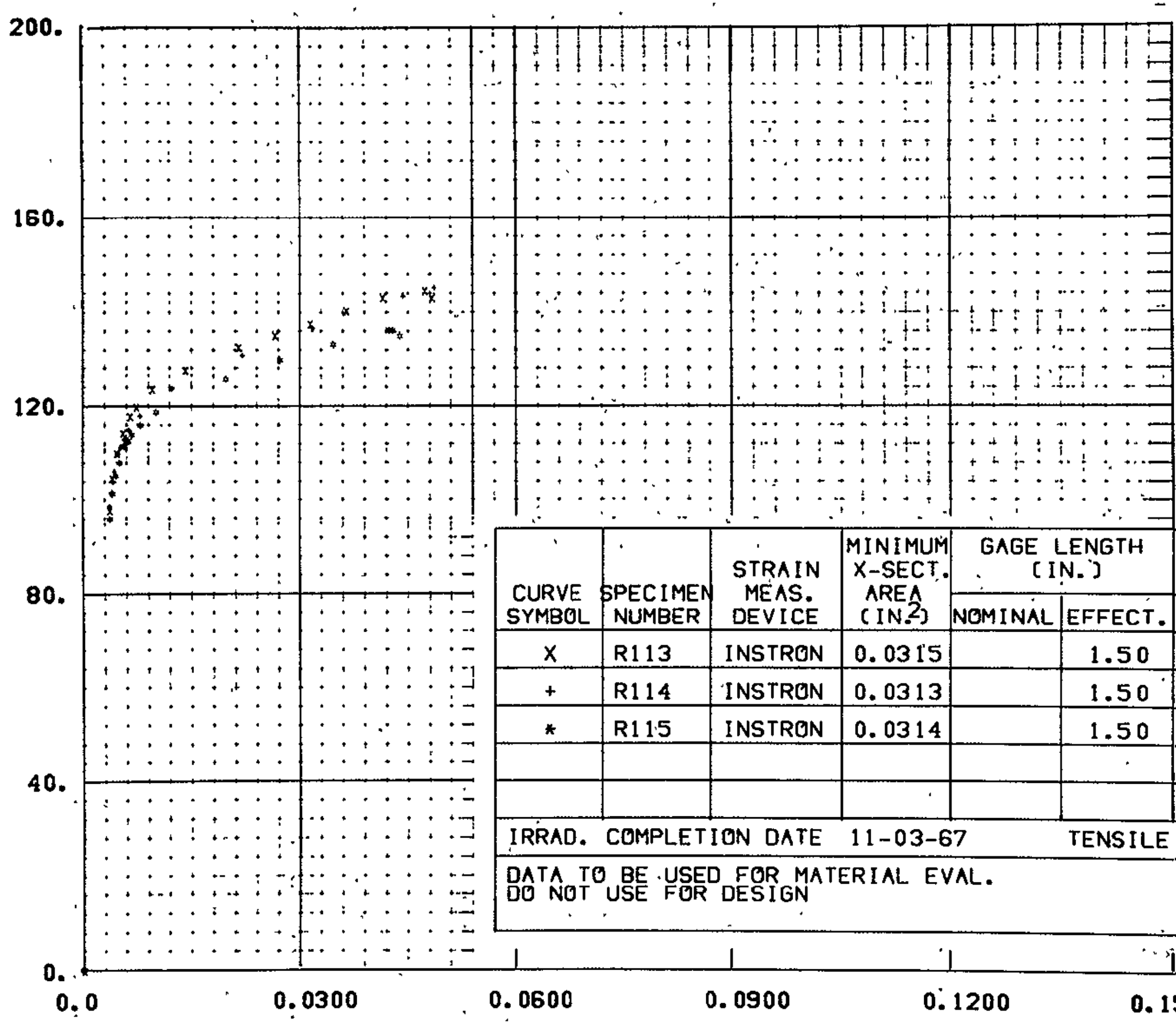
CURVE SYMBOL	SPECIMEN NUMBER	STRAIN MEAS. DEVICE	MINIMUM X-SECT. AREA ($IN.^2$)	GAGE LENGTH (IN.)		FLUENCE ($NEUTRONS/CM^2$)		GAMMA DOSE (ERGS/ GM(C))
				NOMINAL	EFFECT.	THERMAL	FAST	
X	R113	INSTRON	0.0315		1.50	2.1+17	8.2+16	9.0+11
+	R114	INSTRON	0.0313		1.50	2.0+17	7.8+16	8.8+11
*	R115	INSTRON	0.0314		1.50	1.9+17	7.4+16	8.6+11

IRRAD. COMPLETION DATE 11-03-67 TENSILE TEST DATE MAR. 68

DATA TO BE USED FOR MATERIAL EVAL.
DO NOT USE FOR DESIGN

FIGURE 6-5 STRESS-STRAIN CURVES FOR RENE 41. MED IRRAD
TESTED AT 1660 R (0.0013 IN./IN./MIN).

NPC 26,914



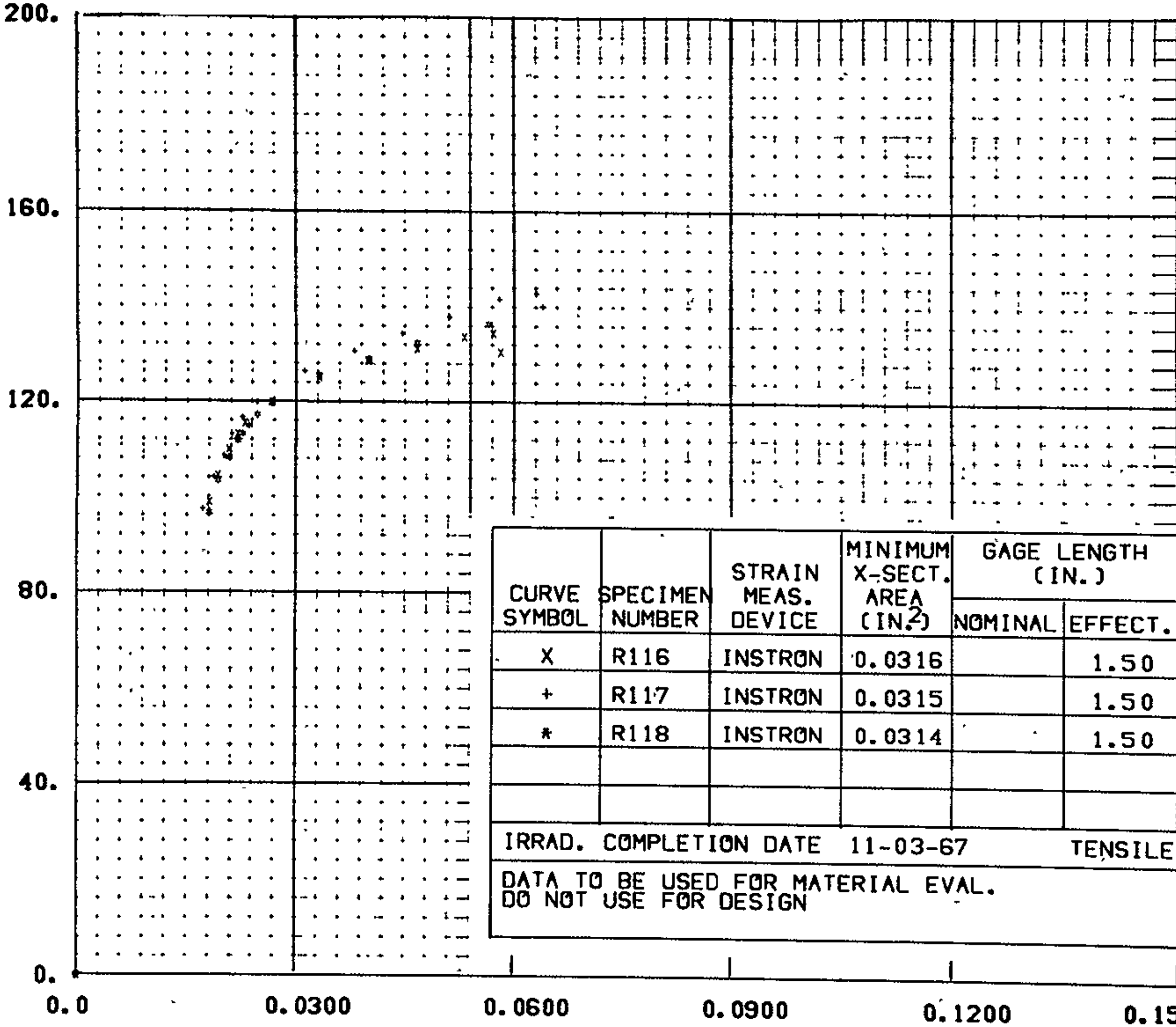
CURVE SYMBOL	SPECIMEN NUMBER	STRAIN MEAS. DEVICE	MINIMUM X-SECT. AREA (IN^2)	GAGE LENGTH (IN.) NOMINAL	GAGE LENGTH (IN.) EFFECT.	FLUENCE ($NEUTRONS/CM^2$) THERMAL	FLUENCE ($NEUTRONS/CM^2$) FAST	GAMMA DOSE (ERGS/GM(C))
X	R113	INSTRON	0.0315		1.50	2.1+17	8.2+16	9.0+11
+	R114	INSTRON	0.0313		1.50	2.0+17	7.8+16	8.8+11
*	R115	INSTRON	0.0314		1.50	1.9+17	7.4+16	8.6+11

IRRAD. COMPLETION DATE 11-03-67 TENSILE TEST DATE MAR. 68

DATA TO BE USED FOR MATERIAL EVAL.
DO NOT USE FOR DESIGN

FIGURE 6-6 STRESS-STRAIN CURVES FOR RENE 41. MED. IRRAD
TESTED AT 1660 R (0.0013 IN./IN./MIN). FITTED TO HDBK MOD

NPC 26,915



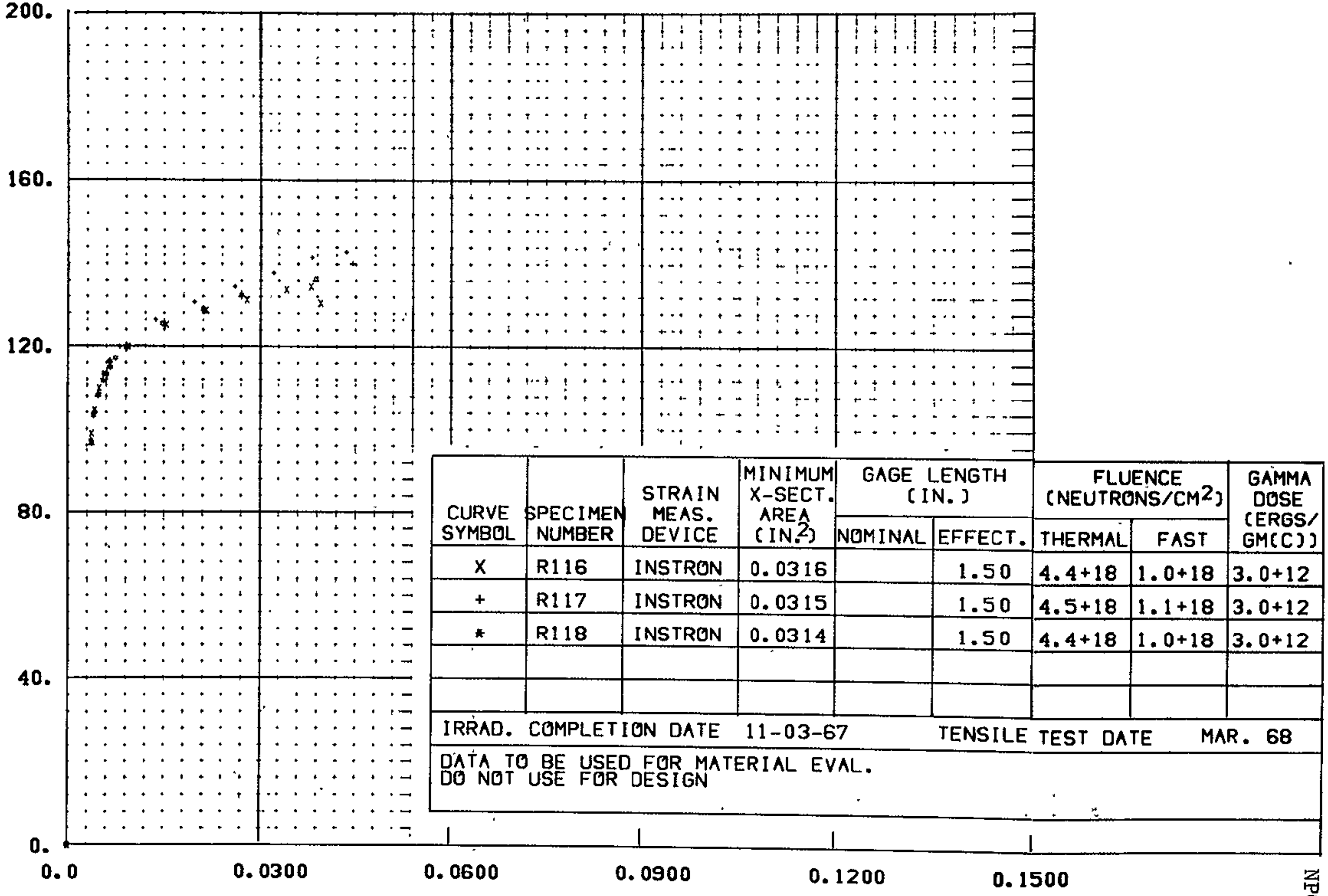
CURVE SYMBOL	SPECIMEN NUMBER	STRAIN MEAS. DEVICE	MINIMUM X-SECT. AREA (IN.^{2})	GAGE LENGTH (IN.) NOMINAL	GAGE LENGTH (IN.) EFFECT.	FLUENCE (NEUTRONS/CM^2) THERMAL	FLUENCE (NEUTRONS/CM^2) FAST	GAMMA DOSE (ERGS/GM(C))
X	R116	INSTRON	0.0316		1.50	4.4+18	1.0+18	3.0+12
+	R117	INSTRON	0.0315		1.50	4.5+18	1.1+18	3.0+12
*	R118	INSTRON	0.0314		1.50	4.4+18	1.0+18	3.0+12

IRRAD. COMPLETION DATE 11-03-67   TENSILE TEST DATE MAR. 68

DATA TO BE USED FOR MATERIAL EVAL.
DO NOT USE FOR DESIGN

FIGURE 6-7 STRESS-STRAIN CURVES FOR RENE 41. HIGH IRRAD
TESTED AT 1660 R (0.0013 IN./IN./MIN).

NPC 26,916



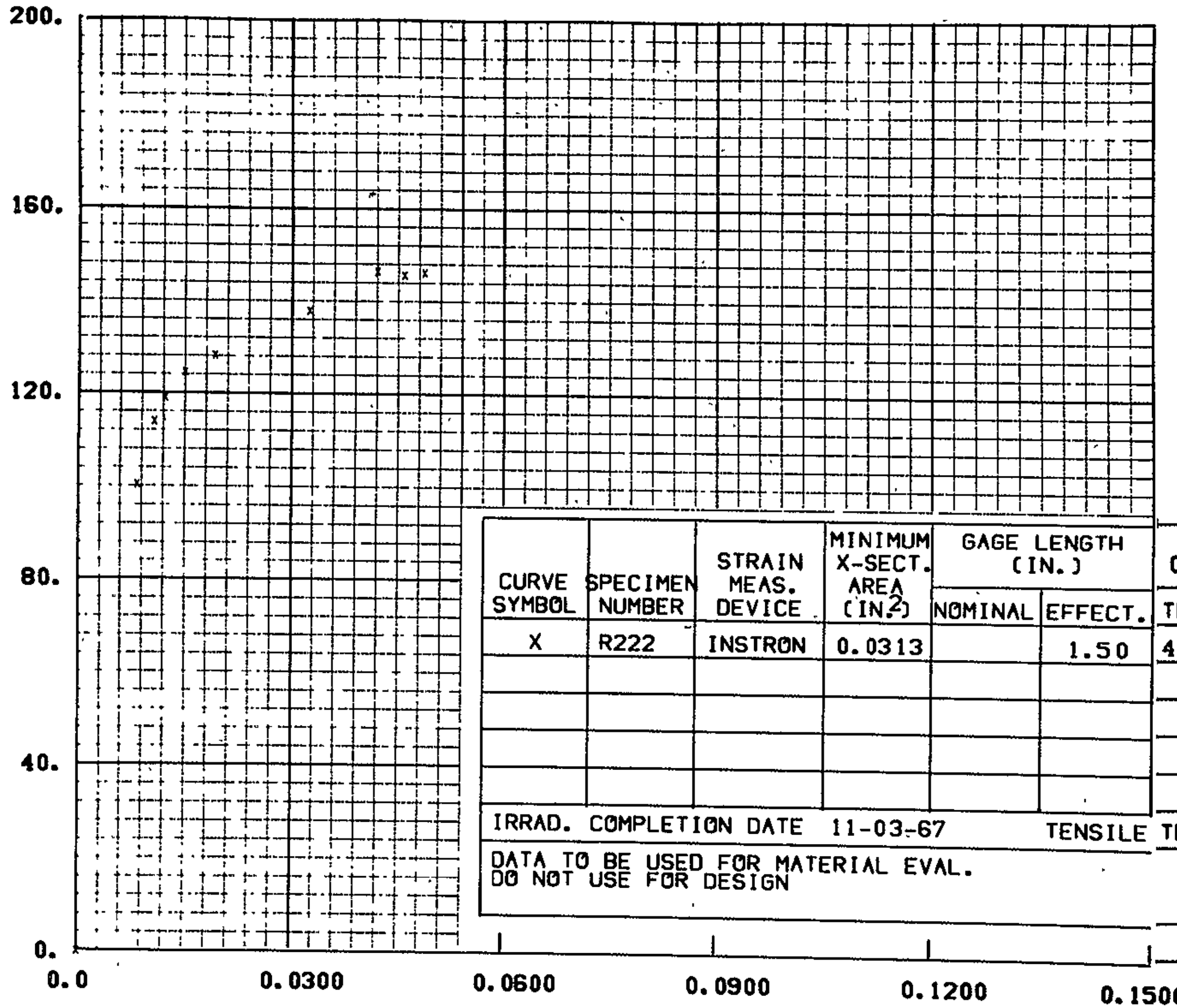
CURVE SYMBOL	SPECIMEN NUMBER	STRAIN MEAS. DEVICE	MINIMUM X-SECT. AREA (IN.^{2})	GAGE LENGTH (IN.) NOMINAL	GAGE LENGTH (IN.) EFFECT.	FLUENCE (NEUTRONS/CM^2) THERMAL	FLUENCE (NEUTRONS/CM^2) FAST	GAMMA DOSE (ERGS/GM(C))
X	R116	INSTRON	0.0316		1.50	4.4+18	1.0+18	3.0+12
+	R117	INSTRON	0.0315		1.50	4.5+18	1.1+18	3.0+12
*	R118	INSTRON	0.0314		1.50	4.4+18	1.0+18	3.0+12

IRRAD. COMPLETION DATE 11-03-67 TENSILE TEST DATE MAR. 68

DATA TO BE USED FOR MATERIAL EVAL.
DO NOT USE FOR DESIGN

FIGURE 6-8 STRESS-STRAIN CURVES FOR RENE 41. HIGH IRRAD
TESTED AT 1660 R (0.0013 IN./IN./MIN). FITTED TO HDBK MOD

NPC 26,917



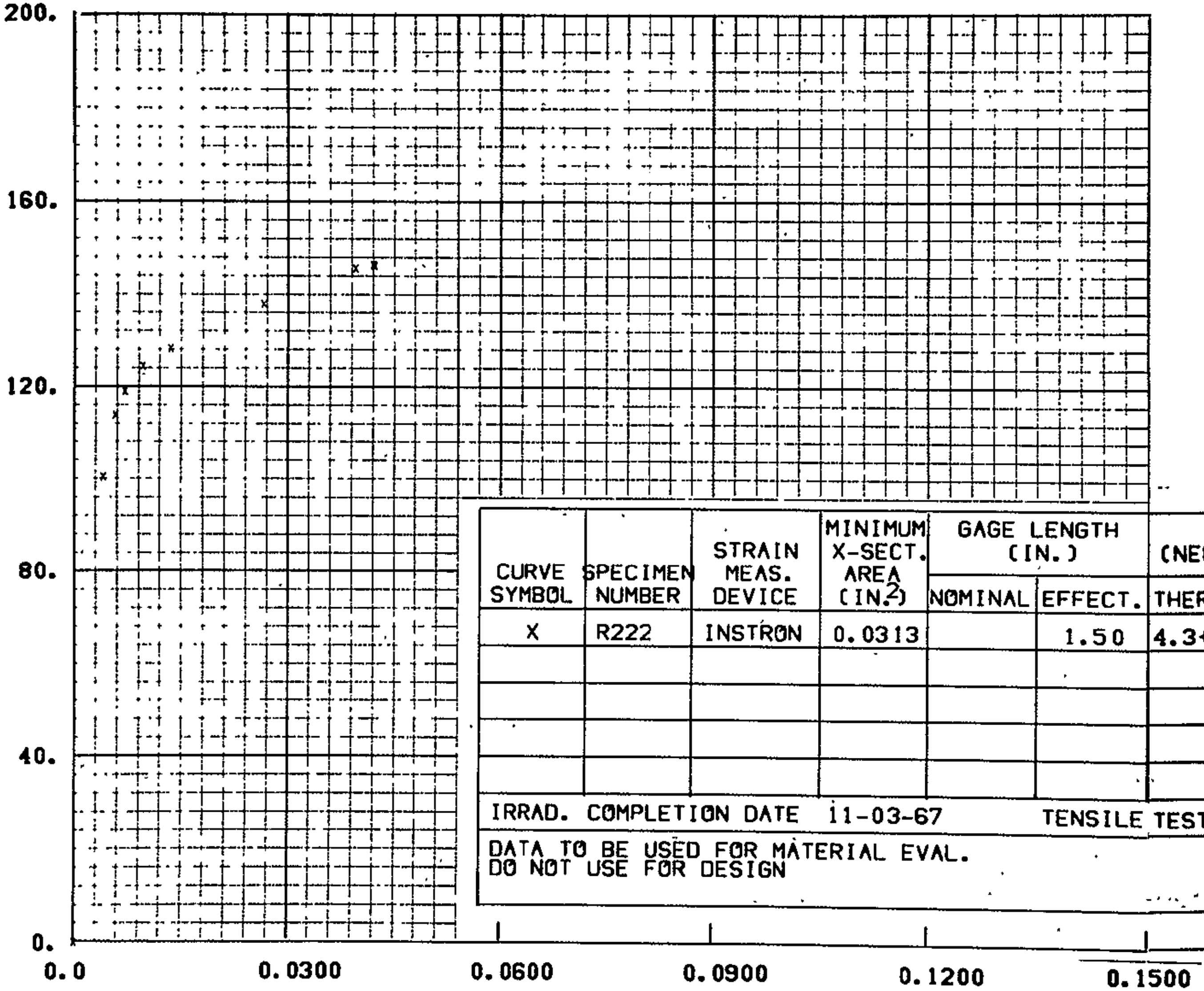
CURVE SYMBOL	SPECIMEN NUMBER	STRAIN MEAS. DEVICE	MINIMUM X-SECT. AREA (IN.^{2})	GAGE LENGTH (IN.) NOMINAL	GAGE LENGTH (IN.) EFFECT.	FLUENCE (NEUTRONS/CM^2) THERMAL	FLUENCE (NEUTRONS/CM^2) FAST	GAMMA DOSE (ERGS/GM(C))
X	R222	INSTRON	0.0313		1.50	4.3+18	1.0+18	2.9+12

IRRAD. COMPLETION DATE 11-03-67 TENSILE TEST DATE APR. 68

DATA TO BE USED FOR MATERIAL EVAL.
DO NOT USE FOR DESIGN

FIGURE 6-9 STRESS-STRAIN CURVES FOR RENE 41. HIGH IRRAD
TESTED AT 1660 R (0.013 IN./IN./MIN).

NPC 26,918.



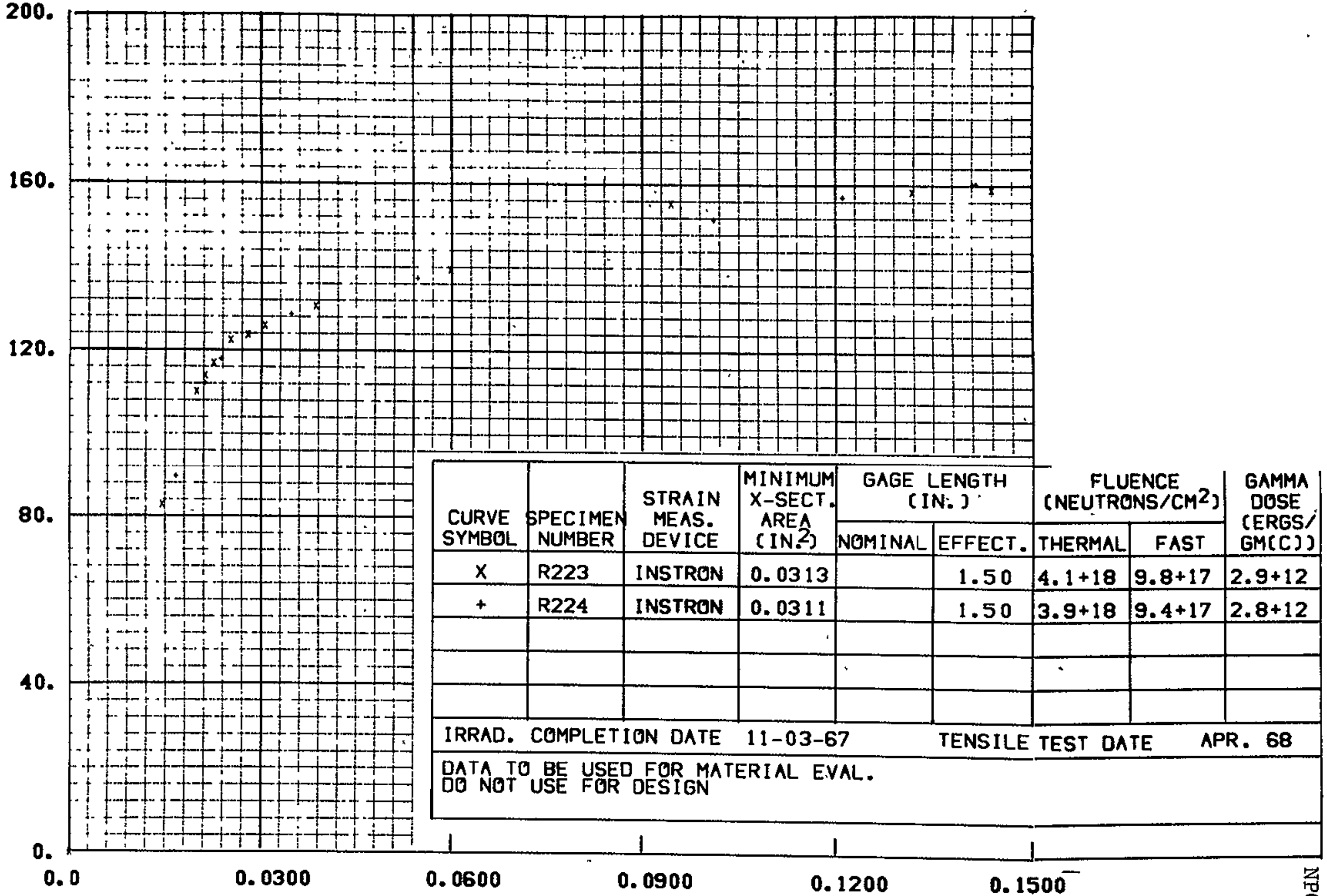
CURVE SYMBOL	SPECIMEN NUMBER	STRAIN MEAS. DEVICE	MINIMUM X-SECT. AREA (IN.^{2})	GAGE LENGTH (IN.) NOMINAL	GAGE LENGTH (IN.) EFFECT.	FLUENCE (NEUTRONS/CM^2) THERMAL	FLUENCE (NEUTRONS/CM^2) FAST	GAMMA DOSE (ERGS/GM(C))
X	R222	INSTRON	0.0313		1.50	4.3+18	1.0+18	2.9+12

IRRAD. COMPLETION DATE 11-03-67 TENSILE TEST DATE APR. 68

DATA TO BE USED FOR MATERIAL EVAL.
DO NOT USE FOR DESIGN

FIGURE 6-10 STRESS-STRAIN CURVES FOR RENE 41. HIGH IRRAD
TESTED AT 1660 R (0.013 IN./IN./MIN). FITTED TO HDBK MOD

NPC 26,919



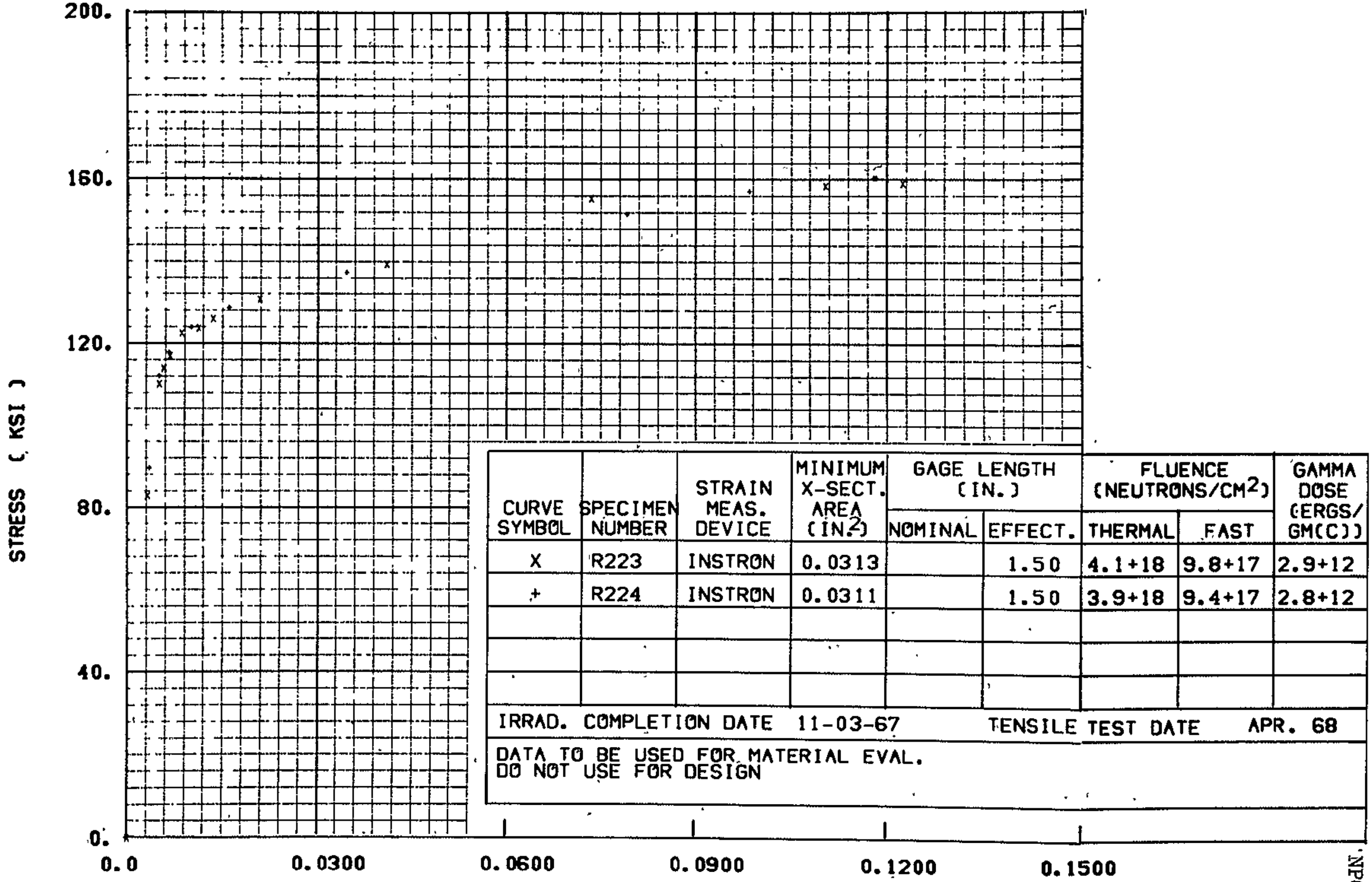
CURVE SYMBOL	SPECIMEN NUMBER	STRAIN MEAS. DEVICE	MINIMUM X-SECT. AREA ($IN.^2$)	GAGE LENGTH (IN.) NOMINAL	GAGE LENGTH (IN.) EFFECT.	FLUENCE (NEUTRONS/CM^2) THERMAL	FLUENCE (NEUTRONS/CM^2) FAST	GAMMA DOSE (ERGS/GM(C))
X	R223	INSTRON	0.0313		1.50	4.1+18	9.8+17	2.9+12
+	R224	INSTRON	0.0311		1.50	3.9+18	9.4+17	2.8+12

IRRAD. COMPLETION DATE 11-03-67 TENSILE TEST DATE APR. 68

DATA TO BE USED FOR MATERIAL EVAL.
DO NOT USE FOR DESIGN

FIGURE 6-11 STRESS-STRAIN CURVES FOR RENE 41. HIGH IRRAD TESTED AT 1660 R (0.13 IN./IN./MIN).

NPC 26,920



CURVE SYMBOL	SPECIMEN NUMBER	STRAIN MEAS. DEVICE	MINIMUM X-SECT. AREA (IN.^{2})	GAGE LENGTH (IN.) NOMINAL	GAGE LENGTH (IN.) EFFECT.	FLUENCE (NEUTRONS/CM^2) THERMAL	FLUENCE (NEUTRONS/CM^2) FAST	GAMMA DOSE (ERGS/GM(C))
X	R223	INSTRON	0.0313		1.50	4.1+18	9.8+17	2.9+12
+	R224	INSTRON	0.0311		1.50	3.9+18	9.4+17	2.8+12

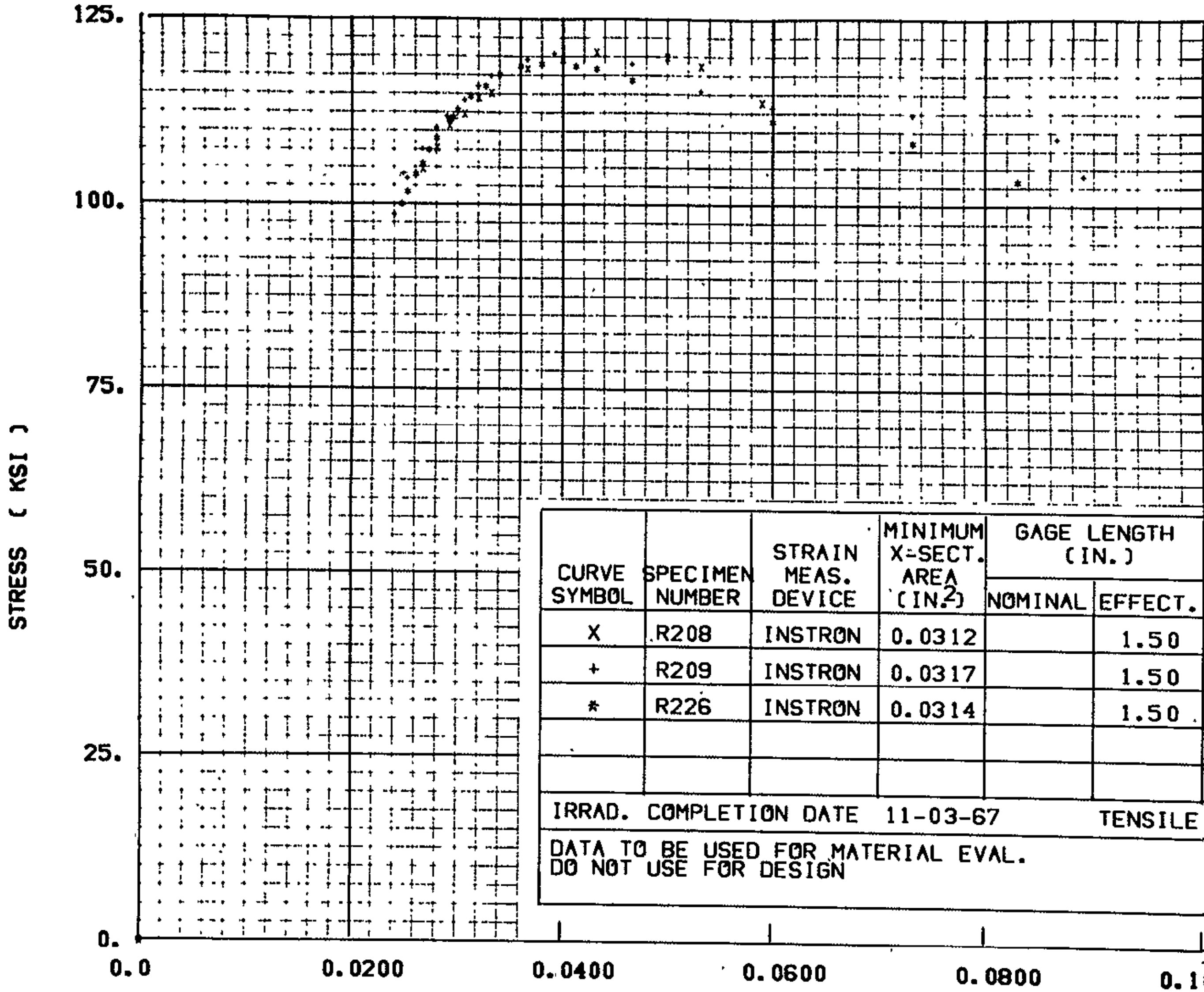
IRRAD. COMPLETION DATE 11-03-67 TENSILE TEST DATE APR. 68

DATA TO BE USED FOR MATERIAL EVAL.
DO NOT USE FOR DESIGN

STRAIN (IN./IN. OF GAGE LENGTH)(BASED ON HANDBOOK MODULUS)

FIGURE 6-12 STRESS-STRAIN CURVES FOR RENE 41. HIGH IRRAD
TESTED AT 1660 R (0.13 IN./IN./MIN). FITTED TO HDBK MOD

NPC 26,921



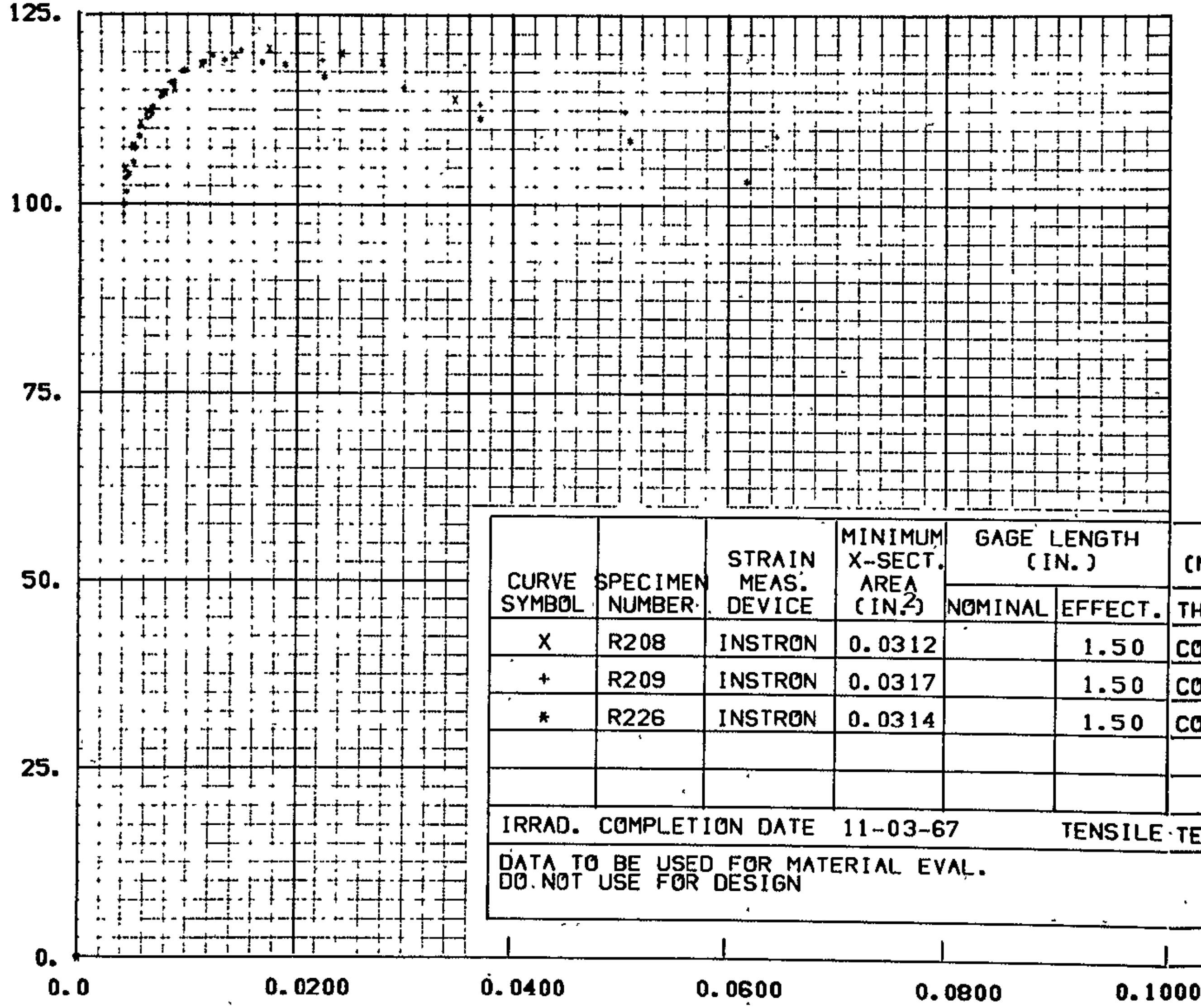
CURVE SYMBOL	SPECIMEN NUMBER	STRAIN MEAS. DEVICE	MINIMUM X-SECT. AREA ($IN.^2$)	GAGE LENGTH (IN.)		FLUENCE (NEUTRONS/CM^2)		GAMMA DOSE (ERGS/GM(C))
				NOMINAL	EFFECT.	THERMAL	FAST	
X	R208	INSTRON	0.0312		1.50	CONT		
+	R209	INSTRON	0.0317		1.50	CONT		
*	R226	INSTRON	0.0314		1.50	CONT		

IRRAD. COMPLETION DATE 11-03-67 TENSILE TEST DATE MAR. 68

DATA TO BE USED FOR MATERIAL EVAL.
DO NOT USE FOR DESIGN

FIGURE 6-13 STRESS-STRAIN CURVES FOR RENE 41. CONTROLS TESTED AT 1860 R (0.0013 IN./IN./MIN).

NPC 26,922



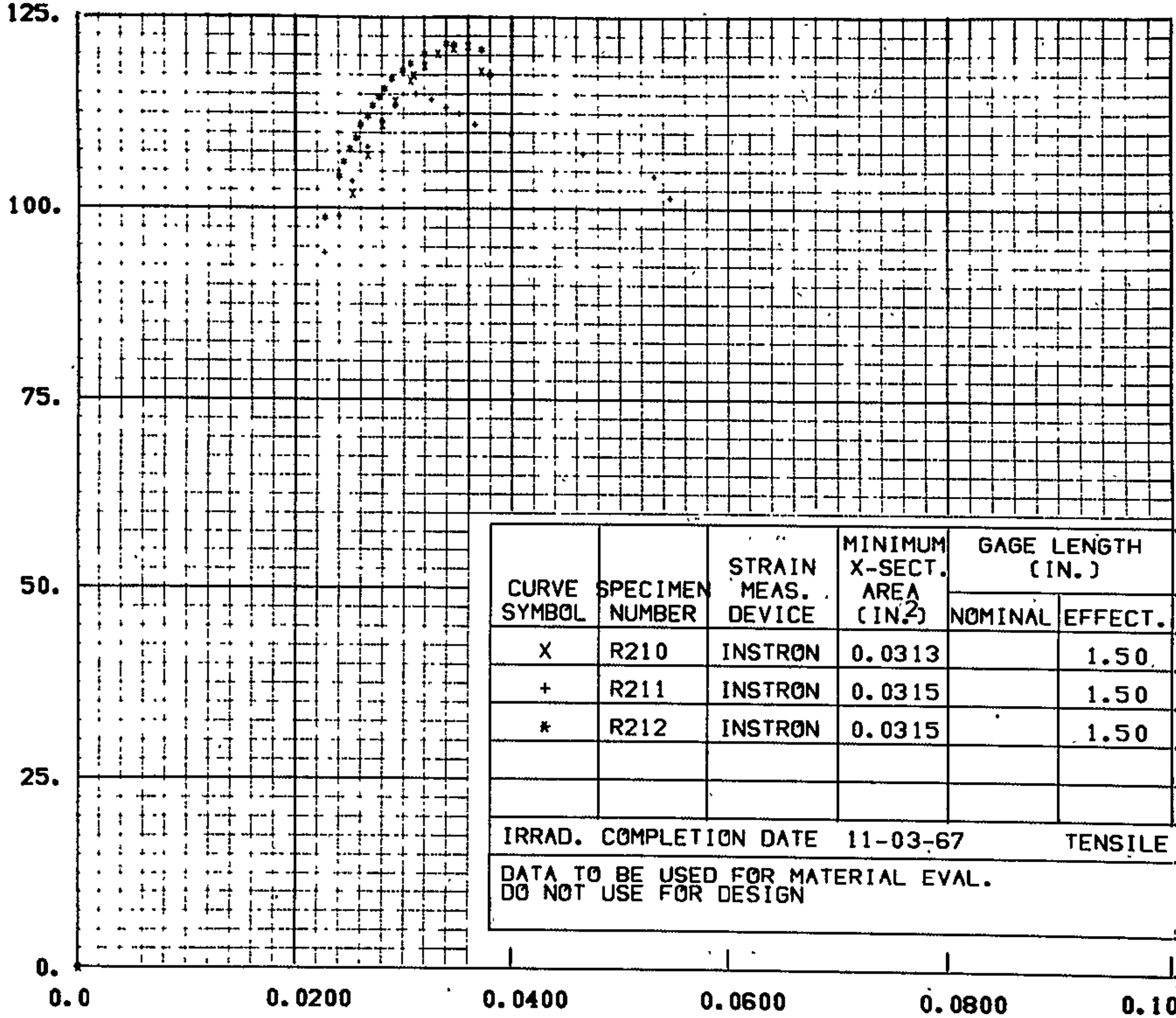
CURVE SYMBOL	SPECIMEN NUMBER	STRAIN MEAS. DEVICE	MINIMUM X-SECT. AREA ($IN.^2$)	GAGE LENGTH (IN.) NOMINAL	GAGE LENGTH (IN.) EFFECT.	FLUENCE (NEUTRONS/CM^2) THERMAL	FLUENCE (NEUTRONS/CM^2) FAST	GAMMA DOSE (ERGS/GM(C))
X	R208	INSTRON	0.0312		1.50	CONT		
+	R209	INSTRON	0.0317		1.50	CONT		
*	R226	INSTRON	0.0314		1.50	CONT		

IRRAD. COMPLETION DATE 11-03-67 TENSILE TEST DATE MAR. 68

DATA TO BE USED FOR MATERIAL EVAL.
DO NOT USE FOR DESIGN

FIGURE 6-14 STRESS-STRAIN CURVES FOR RENE 41. CONTROLS TESTED AT 1860 R (0.0013 IN./IN./MIN). FITTED TO HDBK MOD

NPC 26,923



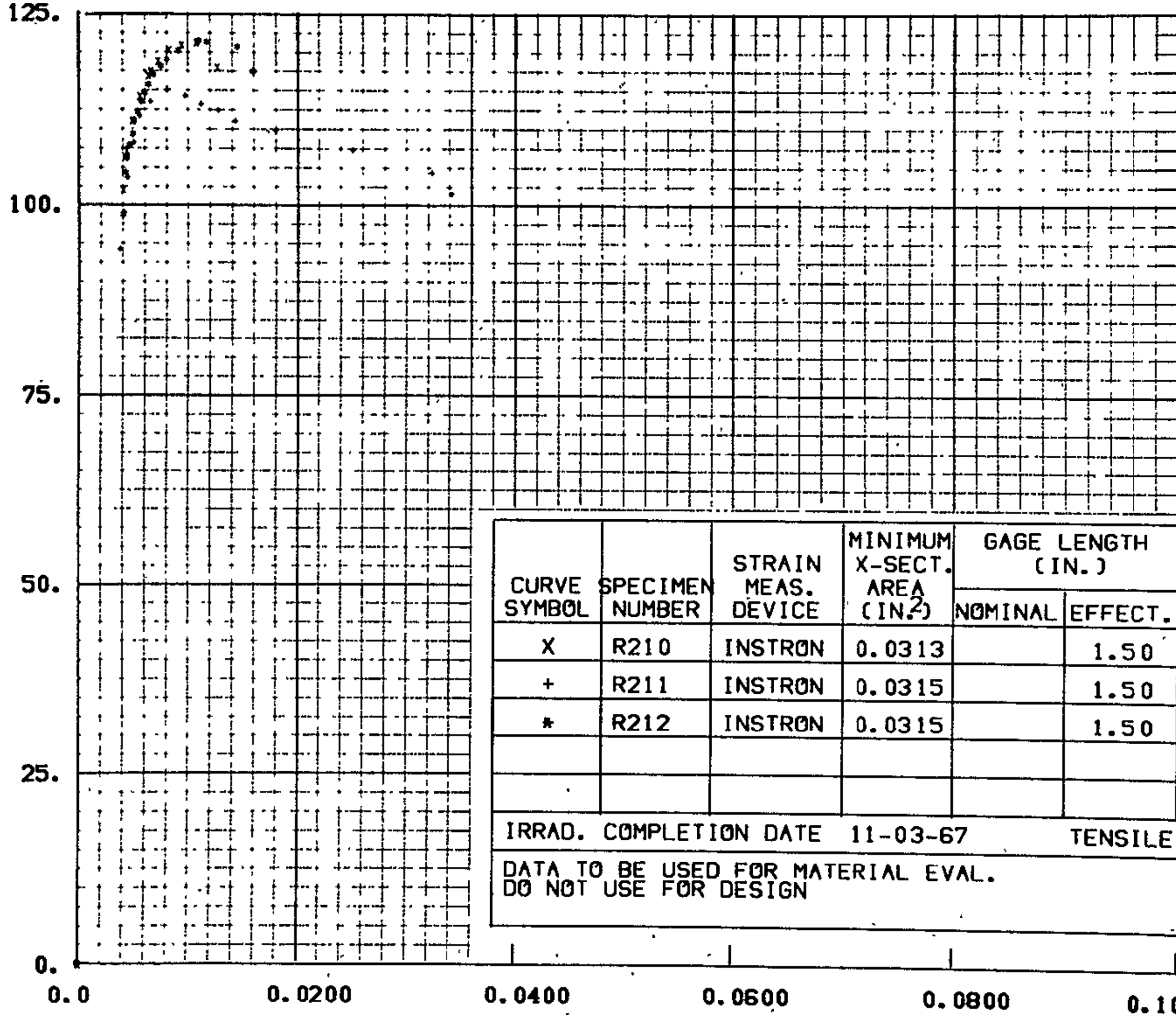
CURVE SYMBOL	SPECIMEN NUMBER	STRAIN MEAS. DEVICE	MINIMUM X-SECT. AREA (IN.^{2})	GAGE LENGTH (IN.) NOMINAL	GAGE LENGTH (IN.) EFFECT.	FLUENCE (NEUTRONS/CM^2) THERMAL	FLUENCE (NEUTRONS/CM^2) FAST	GAMMA DOSE (ERGS/GM(C))
X	R210	INSTRON	0.0313		1.50	9.2+15	5.2+15	2.4+11
+	R211	INSTRON	0.0315		1.50	9.2+15	5.3+15	2.5+11
*	R212	INSTRON	0.0315		1.50	9.0+15	5.2+15	2.4+11

IRRAD. COMPLETION DATE 11-03-67 TENSILE TEST DATE MAR. 68

DATA TO BE USED FOR MATERIAL EVAL.
DO NOT USE FOR DESIGN

FIGURE 6-15 STRESS-STRAIN CURVES FOR RENE 41. LOW IRRAD
TESTED AT 1860 R (0.0013 IN./IN./MIN).

NPC 26,924



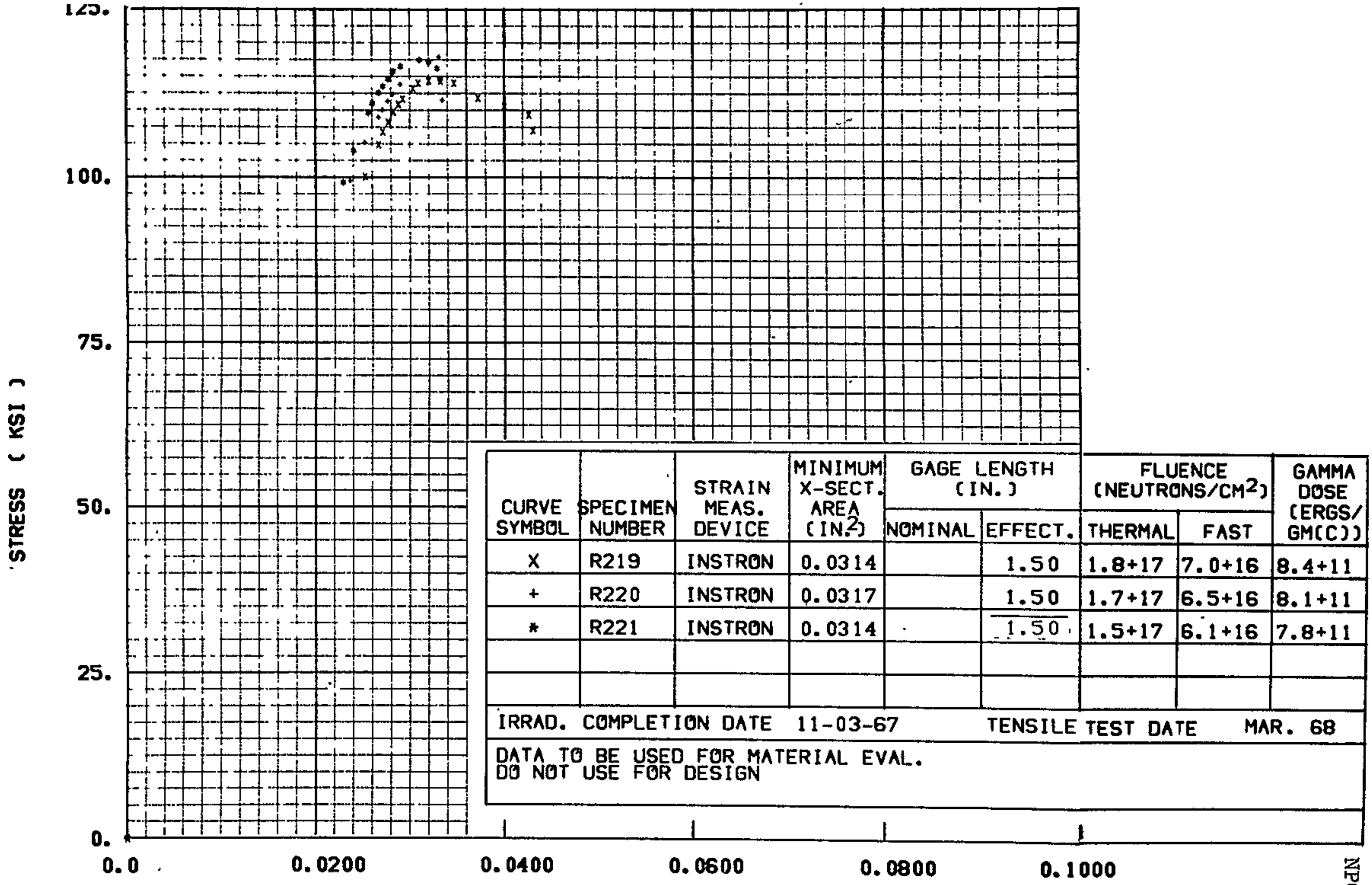
CURVE SYMBOL	SPECIMEN NUMBER	STRAIN MEAS. DEVICE	MINIMUM X-SECT. AREA ($IN.^2$)	GAGE LENGTH (IN.) NOMINAL	GAGE LENGTH (IN.) EFFECT.	FLUENCE (NEUTRONS/CM^2) THERMAL	FLUENCE (NEUTRONS/CM^2) FAST	GAMMA DOSE (ERGS/GM(C))
X	R210	INSTRON	0.0313		1.50	9.2+15	5.2+15	2.4+11
+	R211	INSTRON	0.0315		1.50	9.2+15	5.3+15	2.5+11
*	R212	INSTRON	0.0315		1.50	9.0+15	5.2+15	2.4+11

IRRAD. COMPLETION DATE 11-03-67 TENSILE TEST DATE MAR. 68

DATA TO BE USED FOR MATERIAL EVAL.
DO NOT USE FOR DESIGN

FIGURE 6-16 STRESS-STRAIN CURVES FOR RENE 41. LOW IRRAD
TESTED AT 1860 R (0.0013 IN./IN./MIN). FITTED TO HDBK MOD

NPC 26,925



CURVE SYMBOL	SPECIMEN NUMBER	STRAIN MEAS. DEVICE	MINIMUM X-SECT. AREA (IN.^{2})	GAGE LENGTH (IN.) NOMINAL	GAGE LENGTH (IN.) EFFECT.	FLUENCE (NEUTRONS/CM^2) THERMAL	FLUENCE (NEUTRONS/CM^2) FAST	GAMMA DOSE (ERGS/GM(C))
X	R219	INSTRON	0.0314		1.50	1.8+17	7.0+16	8.4+11
+	R220	INSTRON	0.0317		1.50	1.7+17	6.5+16	8.1+11
*	R221	INSTRON	0.0314		1.50	1.5+17	6.1+16	7.8+11

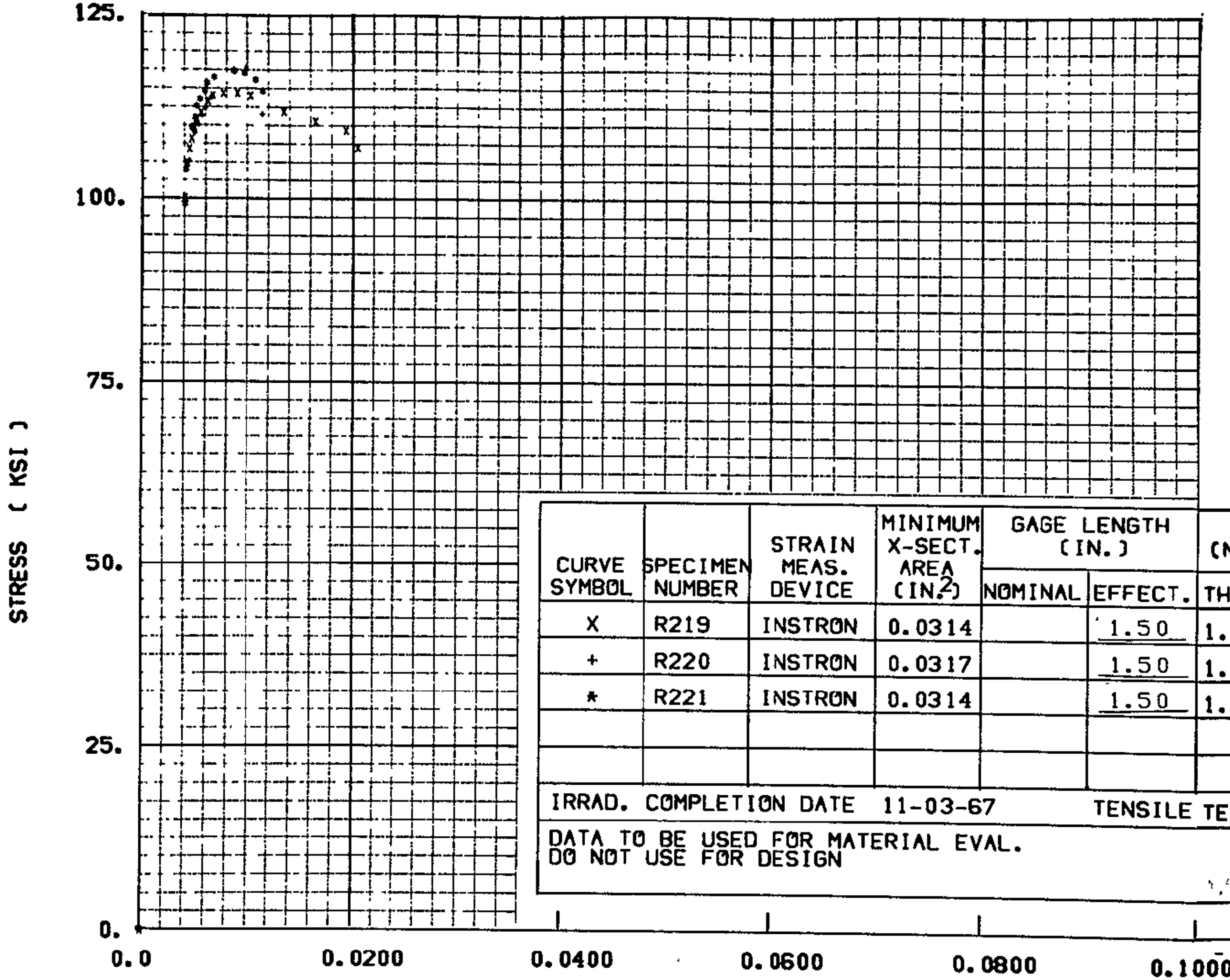
IRRAD. COMPLETION DATE 11-03-67 TENSILE TEST DATE MAR. 68

DATA TO BE USED FOR MATERIAL EVAL.
DO NOT USE FOR DESIGN

STRAIN (IN./IN. OF GAGE LENGTH)(BASED ON CROSSHEAD TRAVEL)

FIGURE 6-17 STRESS-STRAIN CURVES FOR RENE 41. MED IRRAD
TESTED AT 1860 R (0.0013 IN./IN./MIN).

NPC 26,926



CURVE SYMBOL	SPECIMEN NUMBER	STRAIN MEAS. DEVICE	MINIMUM X-SECT. AREA ($IN.^2$)	GAGE LENGTH (IN.) NOMINAL	GAGE LENGTH (IN.) EFFECT.	FLUENCE ($NEUTRONS/CM^2$) THERMAL	FLUENCE ($NEUTRONS/CM^2$) FAST	GAMMA DOSE (ERGS/GM(C))
X	R219	INSTRON	0.0314		1.50	1.8+17	7.0+16	8.4+11
+	R220	INSTRON	0.0317		1.50	1.7+17	6.5+16	8.1+11
*	R221	INSTRON	0.0314		1.50	1.5+17	6.1+16	7.8+11

IRRAD. COMPLETION DATE 11-03-67 TENSILE TEST DATE MAR. 68

DATA TO BE USED FOR MATERIAL EVAL.
DO NOT USE FOR DESIGN

FIGURE 6-18 STRESS-STRAIN CURVES FOR RENE 41. MED IRRAD
TESTED AT 1860 R (0.0013 IN./IN./MIN). FITTED TO HDBK MOD

Section 6.3

Presentation of
Waspaloy Tensile Data

PRECEDING PAGE BLANK NOT FILMED

INDEX TO WASPALOY TENSILE DATA

Condition	Test Temp (°R)	Spec. No.	Instron Data Table	Instron Data Page	Stat. Comparisons Abs. Value Table	Stat. Comparisons Abs. Value Page	Stat. Comparisons % Change Table	Stat. Comparisons % Change Page	Stress-Strain Curves Measured Fig.	Stress-Strain Curves Measured Page	Stress-Strain Curves Fitted Fig.	Stress-Strain Curves Fitted Page
Contr	1560	W 01	6-4	6-42	6-5	6-46	6-6	6-48	6-19	6-50	6-20	6-51
		W 02				6-47		6-49				
		W 03										
Med Irrad	1560	W 04							6-21	6-52	6-22	6-53
		W 07										
		W 10										
Contr	1660	W 12							6-23	6-54	6-24	6-55
		W 13										
		W 16										
Low Irrad	1660	W 17							6-25	6-56	6-26	6-57
		W 18										
		W 19										
Med Irrad	1660	W 20[a]		6-43					6-27	6-58	6-28	6-59
		W 21										
		W 22										
High Irrad	1660	W 23							6-29	6-60	6-30	6-61
		W 24										
		W 26										
Contr	1660	W 67[b]							6-31	6-62	6-32	6-63
		W 68[b]										
		W 70[b]										
Irrad	1660	W 44[b]							6-33	6-64	6-34	6-65
		W 45[b]										
		W 46[b]										
Contr	1860	W 27		6-44					6-35	6-66	6-36	6-67
		W 28										
		W 29										
Low Irrad	1860	W 30							6-37	6-68	6-38	6-69
		W 31										
		W 32										
Med Irrad	1860	W 34							6-39	6-70	6-40	6-71
		W 36										
		W 37										
High Irrad	1860	W 39							6-41	6-72	6-42	6-73
		W 40										
		W 43										

[a] Specimen bent on loading

[b] Pulled at strain rate of 0.13 in./in./min; all others pulled at rate of 0.0013 in./in./min

PRECEDING PAGE BLANK NOT FILMED

Table 6-4

TENSILE TEST DATA FOR INDIVIDUAL SPECIMENS OF WASPALOY

Specimen configuration: round-unnotched - AGC Dwg. 1134298-1. Data to be used for material evaluation only. Do not use for design.

Specimen Number	Condition	Strain Rate (in./in./min)	Test Temp (°R)	0.2% Offset Yield Stress (ksi)	Max Stress (ksi)	Frac Stress (ksi)	% Elongation		% Area Reduct (Bench)	Frac Location	Hardness, Rockwell C		Radiation Exposure		
							Bench	Chart			Pre-Test	Post-Test	Gamma Dose [ergs/g(C)]	Neutron Fluence (n/cm^2) E > 1 MeV	E < 0.48 eV
W 01	Control	0.0013	1560	99.39	162.39	148.24	25.95	26.16	27.99	(1) T					
W 02				97.90	162.83	149.40	28.05	27.87	27.39	(2) T	36.6	35.3			
W 03				97.55	157.55	134.77	32.45	31.94	35.08	(1) T					
Average				98.28	160.92	144.14	28.82	28.66	30.15						
Std Dev				0.98	2.93	8.13	3.32	2.97	4.28						
% Std Dev				0.99	1.82	5.64	11.5	10.4	14.2						
W 04	Irrad	0.0013	1560	97.51	157.75	146.43	25.00	24.54	26.23	(1) T	37.2	34.8	8.7(11)	9.00(16)	2.27(17)
W 07				101.72	163.01	161.40	21.03	19.92	21.95	(2) T			9.0(11)	9.70(16)	2.51(17)
W 10				96.32	157.47	147.93	25.5	24.41	23.18	(1) T			9.4(11)	1.01(17)	2.73(17)
Average				98.52	159.41	151.92	23.84	22.96	23.79						
Std Dev				2.84	3.12	8.24	2.45	2.63	2.20						
% Std Dev				2.88	1.96	5.43	10.3	11.5	9.26						
W 12	Control	0.0013	1660	98.21	135.65	105.09	27.31	27.67	38.08	(1) T	36.7	35.3			
W 13				99.51	138.74	119.13	22.97	23.19	29.72	(1) T					
W 16				99.18	139.38	119.45	23.05	22.95	31.25	(1) O					
Average				98.97	137.92	114.56	24.44	24.60	33.02						
Std Dev				0.68	1.99	8.20	2.48	2.66	4.45						
% Std Dev				0.68	1.45	7.16	10.2	10.8	13.5						
W 17	Irrad	0.0013	1660	100.56	137.99	126.44	18.33	17.52	22.17	(1) T			2.4(11)	5.10(15)	8.8(15)
W 18				99.67	139.38	127.64	20.14	20.67	23.19	(1) T	36.6	34.9	2.3(11)	4.95(15)	8.6(15)
W 19				97.57	140.44	133.25	15.93	16.28	18.59	(2) O			2.3(11)	4.70(15)	8.3(15)
Average				99.27	139.27	129.11	18.13	18.16	21.32						
Std Dev				1.54	1.23	3.64	2.11	2.26	2.42						
% Std Dev				1.55	0.88	2.82	11.6	12.5	11.3						

Strain values are based on Instron cross head travel, not extensometer measurements
Strain rates are average values for the plastic region based on cross head speed and a 1.50-in. gage length.

Table 6-4 (Cont'd)

Specimen Number	Condition	Strain Rate (in./in./min)	Test Temp (^oR)	0.2% Offset Yield Stress (ksi)	Max Stress (ksi)	Frac Stress (ksi)	% Elongation		% Area Reduct (Bench)	Frac Location	Hardness, Rockwell C		Radiation Exposure		
													Gamma Dose [ergs/g(C)]	Neutron Fluence (n/cm^2)	
							Bench	Chart			Pre-Test	Post-Test		E >1 MeV	E < 0.48 eV
W 20	Irrad	0.0013	1660	Bent on Loading											
W 21				99.97	132.50	124.88	16.01	15.55	19.24	(4) T	37.2	34.8	10.0(11)	1.07(17)	2.80(17)
W 22				97.72	138.22	128.92	18.33	17.72	21.23	(1) T			9.7(11)	1.00(17)	2.61(17)
Average				98.85	135.36	126.90	17.17	16.64	20.24						
Std Dev				1.59	4.04	2.86	1.64	1.53	1.41						
% Std Dev				1.61	2.99	2.25	9.55	9.22	6.95						
W 23	Irrad	0.0013	1660	98.68	137.03	133.69	13.91	13.61	22.57	(3) T	36.6	33.0	2.8(12)	8.70(17)	3.65(18)
W 24				96.93	136.88	131.88	13.93	13.83	18.31	(3) T			2.7(12)	8.10(17)	3.40(18)
W 26				93.42	137.03	132.10	13.45	13.65	19.01	(1) T			2.7(12)	7.40(17)	3.14(18)
Average				96.34	136.98	132.56	13.76	13.70	19.96						
Std Dev				2.68	0.09	0.99	0.27	0.12	2.28						
% Std Dev				2.78	0.06	0.75	1.97	0.86	11.4						
W 67	Control	0.13	1660	98.62	165.61	162.55	20.95	21.54	30.77	(1) O					
W 68				98.22	162.20	157.40	22.01	22.17	26.53	(1) T	35.8	35.8			
W 70				99.39	162.67	156.60	21.89	21.65	27.89	(2) O					
Average				98.74	163.49	158.85	21.62	21.79	28.40						
Std Dev				0.59	1.85	3.23	0.58	0.34	2.16						
% Std Dev				0.60	1.13	2.03	2.69	1.54	7.62						
W 44	Irrad	0.13	1660	95.88	160.75	157.56	23.54	22.03	29.59	(1) T			1.1(12)	1.39(17)	3.80(17)
W 45				95.52	161.07	155.47	22.23	22.65	25.95	(2) T	35.8	35.5	1.2(12)	1.36(17)	3.79(17)
W 46				79.34	162.20	162.20	14.91	13.04	27.81	(4) T			1.2(12)	1.15(17)	3.46(17)
Average				90.25	161.34	158.41	20.23	19.24	27.78						
Std Dev				9.45	0.76	3.44	4.65	5.38	1.82						
% Std Dev				10.47	0.47	2.17	23.0	28.0	6.55						

Table 6-4 (Cont'd)

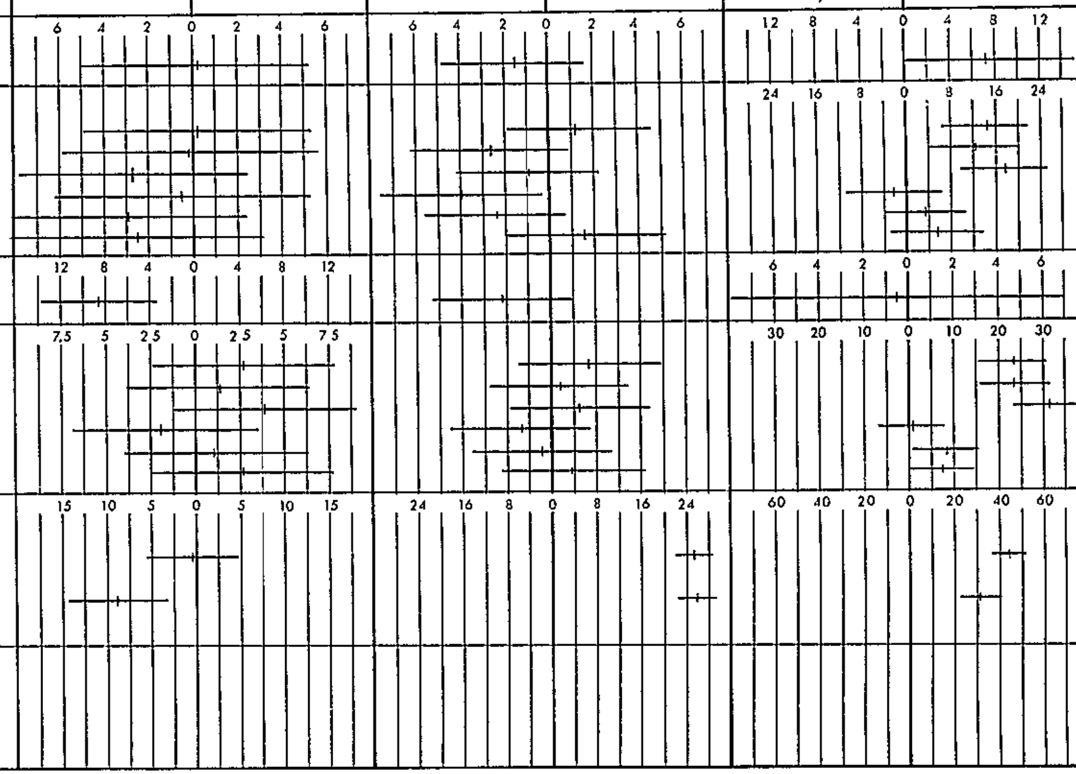
Specimen Number	Condition	Strain Rate (in./in./min)	Test Temp (^oR)	0.2% Offset Yield Stress (ksi)	Max Stress (ksi)	Frac Stress (ksi)	% Elongation		% Area Reduct (Bench)	Frac Loca-tion	Hardness, Rockwell C		Radiation Exposure		
													Gamma Dose [ergs/g(C)]	Neutron Fluence (n/cm^2)	
							Bench	Chart			Pre-Test	Post-Test		E > 1 MeV	E < 0.48 eV
W 27	Control	0.0013	1860	85.33	88.21	57.53	21.35	21.15	19.62	(1) T	35.9	34.2			
W 28				81.99	84.56	47.43	19.73	22.22	25.31	(1) T					
W 29				80.62	83.66	51.51	18.25	17.82	24.36	(2) T					
Average				82.65	85.48	52.16	19.78	20.40	23.10						
Std Dev				2.42	2.41	5.08	1.55	2.29	3.05						
% Std Dev				2.93	2.82	9.74	7.84	11.2	13.2						
W 30	Irrad	0.0013	1860	79.34	83.50	67.50	11.55	11.50	16.32	(2) T			2.2(11)	4.50(15)	8.10(15)
W 31				86.70	87.66	80.46	7.70	7.33	13.09	(2) O			2.2(11)	4.30(15)	7.80(15)
W 32				90.35	90.51	78.45	8.59	7.74	16.82	(1) T	36.5	35.4	2.1(11)	4.10(15)	7.60(15)
Average				85.46	87.22	75.47	9.28	8.86	15.41						
Std Dev				5.61	3.53	6.98	2.02	2.30	2.02						
% Std Dev				6.56	4.04	9.24	21.7	25.9	13.1						
W 34	Irrad	0.0013	1860	83.35	85.33	74.76	7.76	6.93	13.67	(1) T	36.1	34.2	9.4(11)	9.40(16)	2.40(17)
W 36				82.29	85.32	79.42	8.12	7.44	10.53	(2) T			9.0(11)	8.60(16)	2.20(17)
W 37				86.25	87.06	74.02	7.07	6.79	12.10	(1) T			1.1(12)	1.31(17)	3.50(17)
Average				83.96	85.90	76.07	7.65	7.05	12.10						
Std Dev				2.05	1.00	2.93	0.53	0.34	1.57						
% Std Dev				2.44	1.17	3.85	6.97	4.85	13.0						
W 39	Irrad	0.0013	1860	88.58	88.74	84.72	5.64	4.65	7.88	(1) T			3.1(12)	1.29(18)	5.60(18)
W 40				84.51	85.02	84.02	5.31	3.91	7.49	(2) T	36.6	35.7	3.2(12)	1.36(18)	6.21(18)
W 43				86.87	86.71	81.90	3.78	2.77	6.43	(2) T			3.2(12)	1.32(18)	5.65(18)
Average				86.65	86.82	83.55	4.91	3.78	7.27						
Std Dev				2.04	1.86	1.47	0.99	0.95	0.75						
% Std Dev				2.36	2.15	1.76	20.2	25.1	10.3						

Statistical Comparisons

Table 6-5

EFFECT OF TEST CONDITIONS ON THE TENSILE PROPERTIES OF WASPALOY-
COMPARISON ON AN ABSOLUTE-VALUE BASIS

Test Temp. (°R)	Strain Rate (in./in./min)	Specimen Data Compared[a]	90% Confidence Interval on Difference Between Averages Compared: 0.2% Offset Yield Stress (ksi)	Maximum Stress (ksi)	Fracture Stress (ksi)
1560	0.0013	Control vs med irrad			
1660	0.0013	Control vs low irrad Control vs med irrad Control vs high irrad Low irrad vs med irrad Low irrad vs high irrad Med irrad vs high irrad			
1660	0.13	Control vs med irrad			
1860	0.0013	Control vs low irrad Control vs med irrad Control vs high irrad Low irrad vs med irrad Low irrad vs high irrad Med irrad vs high irrad			
1660	As compared	Control 0.0013 vs 0.13 in./in./min Medium irradiation 0.0013 vs 0.13 in./in./min			



[a]Comparison is always second condition compared to the first condition.

Table 6-5 (Cont'd)

Test Temp. (°R)	Strain Rate (in./in./min)	Specimen Data Compared[a]	90% Confidence Interval on Difference Between Averages Compared		
			% Elongation - Bench (-) 0 (+)	% Elongation - Chart (-) 0 (+)	% Area Reduction (-) 0 (+)
1560	0.0013	Control vs med irrad	7.5 5 2.5 0 2.5 5 7.5	7.5 5 2.5 0 2.5 5 7.5	7.5 5 2.5 0 2.5 5 7.5
1660	0.0013	Control vs low irrad Control vs med irrad Control vs high irrad Low irrad vs med irrad Low irrad vs high irrad Med irrad vs high irrad	12 8 4 0 4 8 12	12 8 4 0 4 8 12	12 8 4 0 4 8 12
1660	0.13	Control vs med irrad	6 4 2 0 2 4 6	6 4 2 0 2 4 6	6 4 2 0 2 4 6
1860	0.0013	Control vs low irrad Control vs med irrad Control vs high irrad Low irrad vs med irrad Low irrad vs high irrad Med irrad vs high irrad	15 10 5 0 5 10 15	15 10 5 0 5 10 15	15 10 5 0 5 10 15
1660	As compared	Control 0.0013 vs 0.13 in./in./min Medium irradiation 0.0013 vs 0.13 in./in./min	6 4 2 0 2 4 6	6 4 2 0 2 4 6	12 8 4 0 4 8 12

[a]Comparison is always second condition compared to the first condition.

Table 6-6

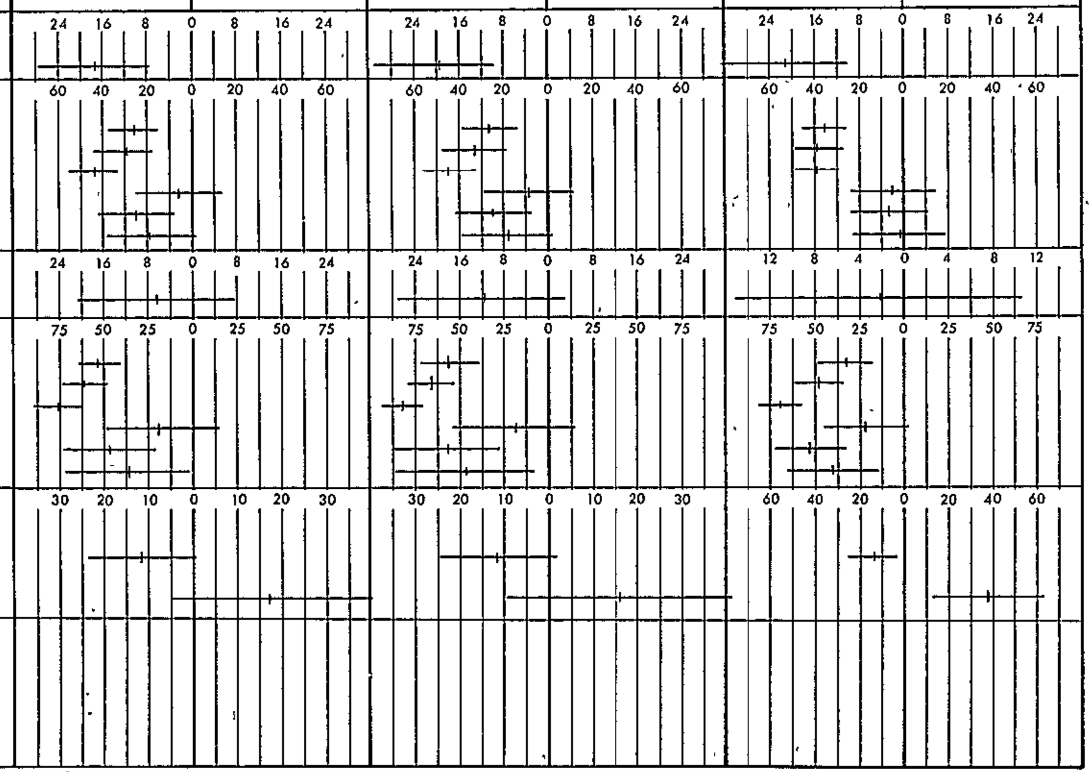
EFFECT OF TEST CONDITIONS ON THE TENSILE PROPERTIES OF WASPALOY - COMPARISON ON A PERCENT-CHANGE BASIS

Test Temp. (°R)	Strain Rate (in./in./min)	Specimen Data Compared[a]	90% Confidence Interval on Difference Between Averages Compared: 0.2% Offset Yield Stress (-) 0 (+)	Maximum Stress (-) 0 (+)	Fracture Stress (-) 0 (+)
1560	0.0013	Control vs med irrad	7.5 5 2.5 0 2.5 5 7.5	3 2 1 0 1 2 3	12 8 4 0 4 8 12
1660	0.0013	Control vs low irrad Control vs med irrad Control vs high irrad Low irrad vs med irrad Low irrad vs high irrad Med irrad vs high irrad		8 4 2 0 2 4 6	24 16 8 0 8 16 24
1660	0.13	Control vs med irrad	12 8 4 0 4 8 12	3 2 1 0 1 2 3	6 4 2 0 2 4 6
1860	0.0013	Control vs low irrad Control vs med irrad Control vs high irrad Low irrad vs med irrad Low irrad vs high irrad Med irrad vs high irrad		6 4 2 0 2 4 6	60 40 20 0 20 40 60
1660	As compared	Control 0.0013 vs 0.13 in./in./min Medium irradiation 0.0013 vs 0.13 in./in./min		24 16 8 0 8 16 24	

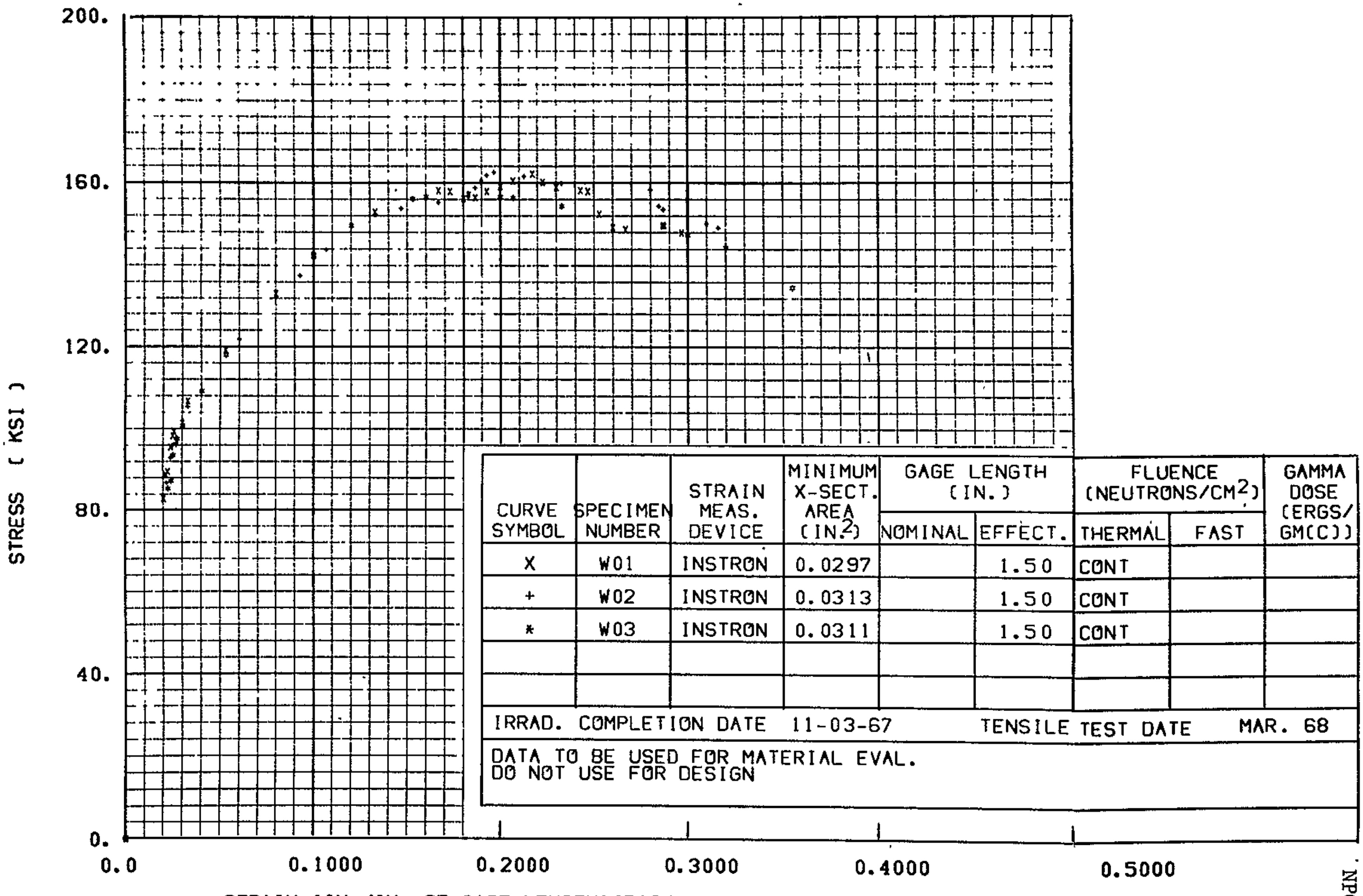
[a] Comparison is always second condition compared to the first condition.

Table 6-6 (Cont'd)

Test Temp. (°R)	Strain Rate (in./in./min)	Specimen Data Compared[a]	90% Confidence Interval on Difference Between Averages Compared: % Elongation - Bench (-) 0 (+)	% Elongation - Chart (-) 0 (+)	% Area Reduction (-) 0 (+)
1560	0.0013	Control vs med irrad			
1660	0.0013	Control vs low irrad Control vs med irrad Control vs high irrad Low irrad vs med irrad Low irrad vs high irrad Med irrad vs high irrad			
1660	0.13	Control vs med irrad			
1860	0.0013	Control vs low irrad Control vs med irrad Control vs high irrad Low irrad vs med irrad Low irrad vs high irrad Med irrad vs high irrad			
1660	As compared	Control 0.0013 vs 0.13 in./in./min Medium irradiation 0.0013 vs 0.13 in./in./min			



[a] Comparison is always second condition compared to the first condition.



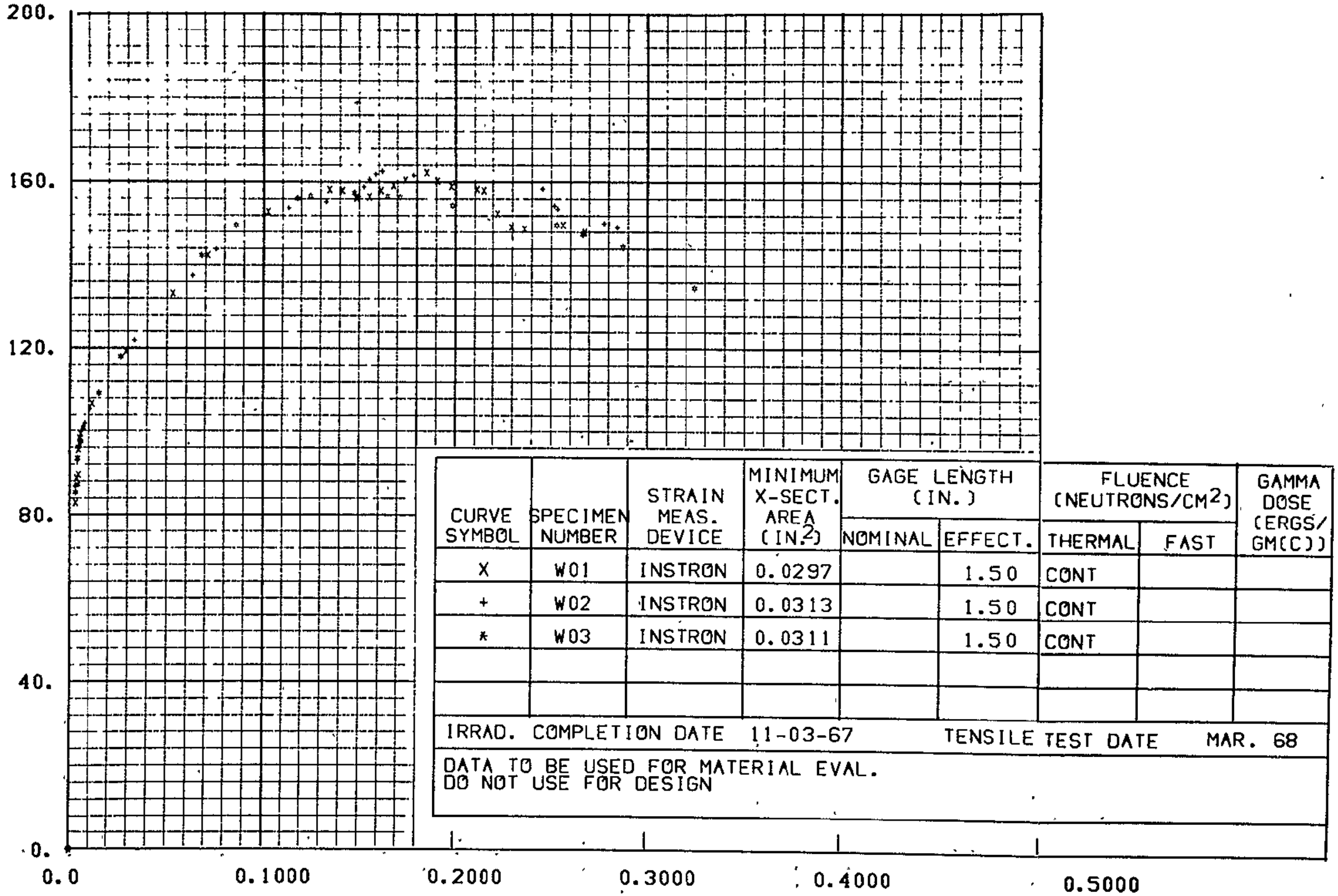
CURVE SYMBOL	SPECIMEN NUMBER	STRAIN MEAS. DEVICE	MINIMUM X-SECT. AREA (IN.2)	GAGE LENGTH (IN.) NOMINAL	GAGE LENGTH (IN.) EFFECT.	FLUENCE (NEUTRONS/CM2) THERMAL	FLUENCE (NEUTRONS/CM2) FAST	GAMMA DOSE (ERGS/GM(C))
X	W01	INSTRON	0.0297		1.50	CONT		
+	W02	INSTRON	0.0313		1.50	CONT		
*	W03	INSTRON	0.0311		1.50	CONT		

IRRAD. COMPLETION DATE 11-03-67 TENSILE TEST DATE MAR. 68

DATA TO BE USED FOR MATERIAL EVAL.
DO NOT USE FOR DESIGN

FIGURE 6-19 STRESS-STRAIN CURVES FOR WASPALOY. CONTROLS TESTED AT 1560 R (0.0013 IN./IN./MIN)

NPC 26,850



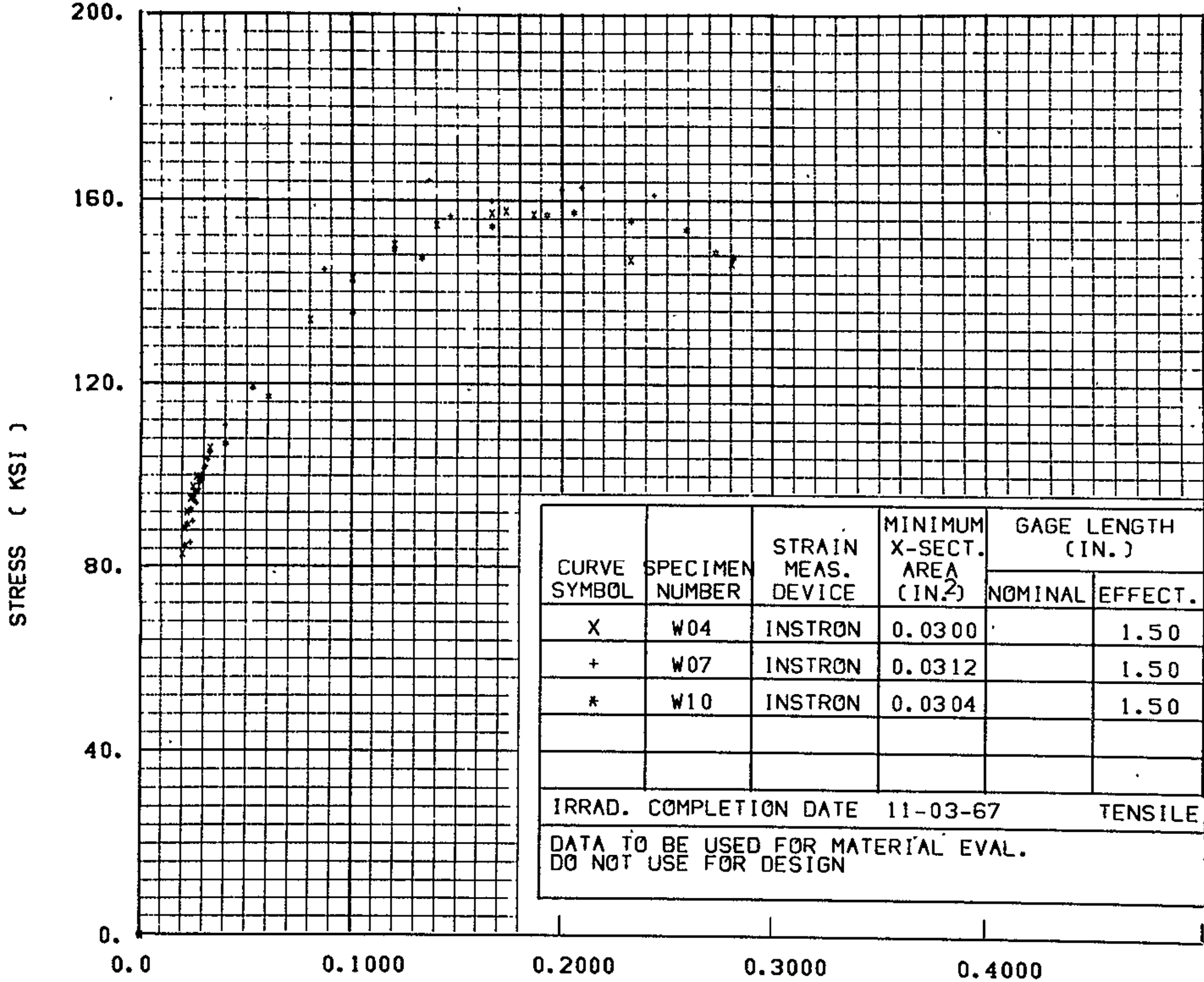
CURVE SYMBOL	SPECIMEN NUMBER	STRAIN MEAS. DEVICE	MINIMUM X-SECT. AREA (IN.^{2})	GAGE LENGTH (IN.) NOMINAL	GAGE LENGTH (IN.) EFFECT.	FLUENCE (NEUTRONS/CM^2) THERMAL	FLUENCE (NEUTRONS/CM^2) FAST	GAMMA DOSE (ERGS/GM(C))
X	W01	INSTRON	0.0297		1.50	CONT		
+	W02	INSTRON	0.0313		1.50	CONT		
*	W03	INSTRON	0.0311		1.50	CONT		

IRRAD. COMPLETION DATE 11-03-67 TENSILE TEST DATE MAR. 68

DATA TO BE USED FOR MATERIAL EVAL.
DO NOT USE FOR DESIGN

FIGURE 6-20 STRESS-STRAIN CURVES FOR WASPALOY. CONTROLS TESTED AT 1560 R (0.0013 IN./IN./MIN), FITTED TO HDBK MOD

NPC 26,851



CURVE SYMBOL	SPECIMEN NUMBER	STRAIN MEAS. DEVICE	MINIMUM X-SECT. AREA (IN.^{2})	GAGE LENGTH (IN.)		FLUENCE (NEUTRONS/CM^2)		GAMMA DOSE (ERGS/GM(C))
				NOMINAL	EFFECT.	THERMAL	FAST	
X	W04	INSTRON	0.0300		1.50	2.3+17	9.0+16	8.7+11
+	W07	INSTRON	0.0312		1.50	2.5+17	9.7+16	9.0+11
*	W10	INSTRON	0.0304		1.50	2.7+17	1.0+17	9.4+11

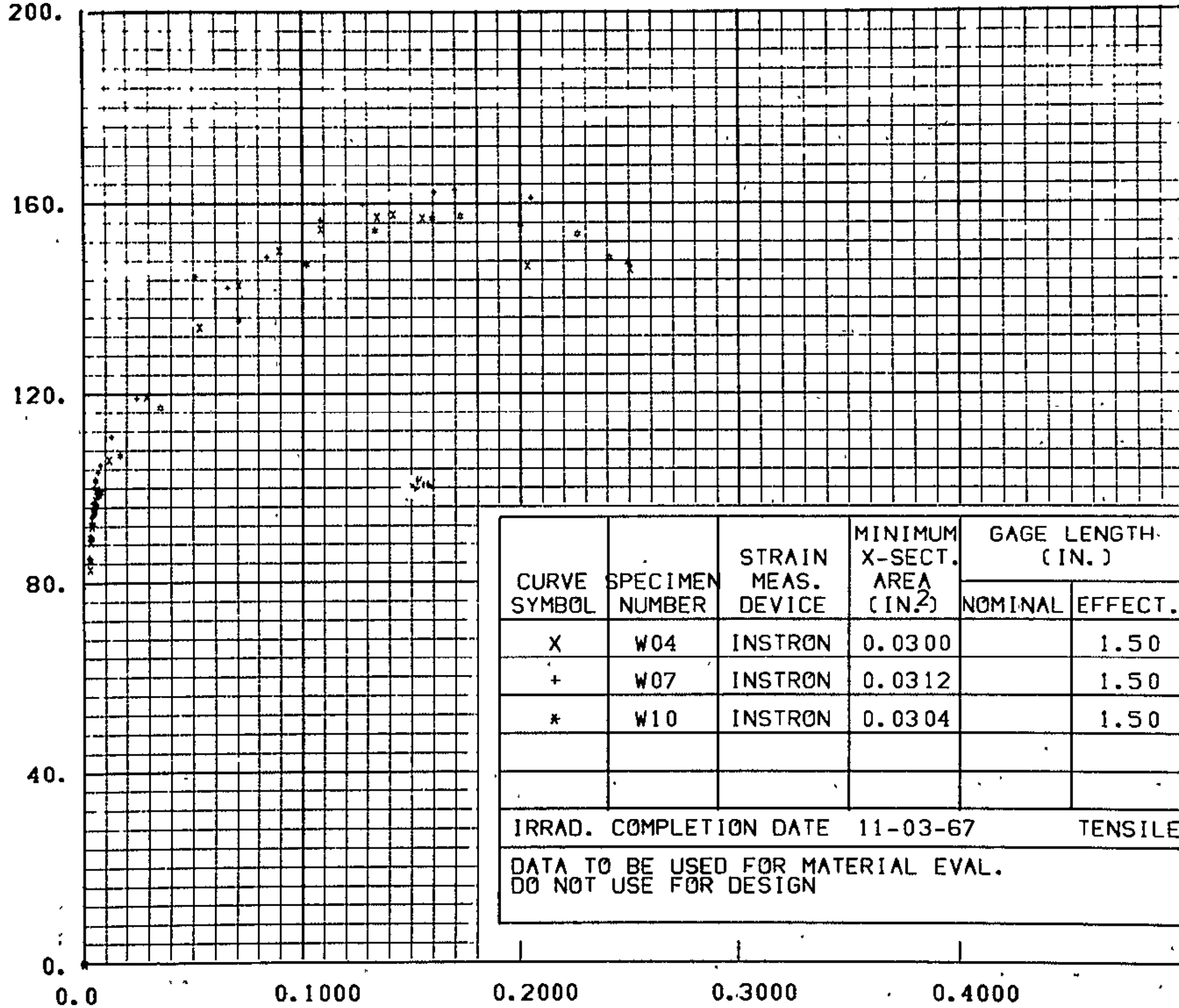
IRRAD. COMPLETION DATE 11-03-67 TENSILE TEST DATE MAR. 68

DATA TO BE USED FOR MATERIAL EVAL.
DO NOT USE FOR DESIGN

STRAIN (IN./IN. OF GAGE LENGTH)(BASED ON CROSSHEAD TRAVEL)

FIGURE 6-21 STRESS-STRAIN CURVES FOR WASPALOY. MED IRRAD
TESTED AT 1560 R (0.0013 IN./IN./MIN)

NPC 26,852



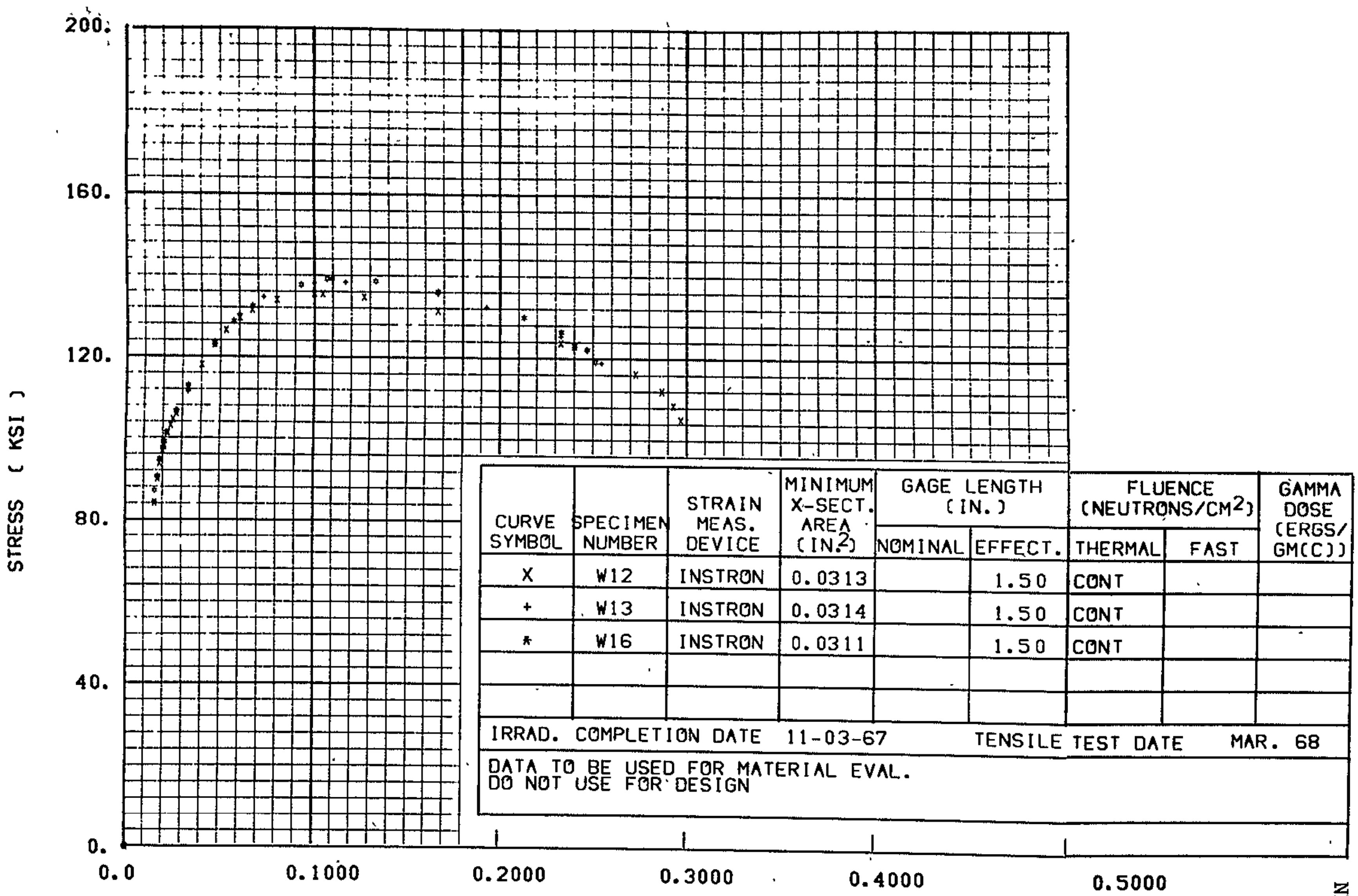
CURVE SYMBOL	SPECIMEN NUMBER	STRAIN MEAS. DEVICE	MINIMUM X-SECT. AREA (IN.2)	GAGE LENGTH (IN.)		FLUENCE (NEUTRONS/CM2)		GAMMA DOSE (ERGS/ GM(C))
				NOMINAL	EFFECT.	THERMAL	FAST	
X	W04	INSTRON	0.0300		1.50	2.3+17	9.0+16	8.7+11
+	W07	INSTRON	0.0312		1.50	2.5+17	9.7+16	9.0+11
*	W10	INSTRON	0.0304		1.50	2.7+17	1.0+17	9.4+11

IRRAD. COMPLETION DATE 11-03-67 TENSILE TEST DATE MAR. 68

DATA TO BE USED FOR MATERIAL EVAL.
DO NOT USE FOR DESIGN

FIGURE 6-22 STRESS-STRAIN CURVES FOR WASPALOY. MED IRRAD
TESTED AT 1560 R (0.0013 IN./IN./MIN). FITTED TO HDBK MOD

NPC 26,853



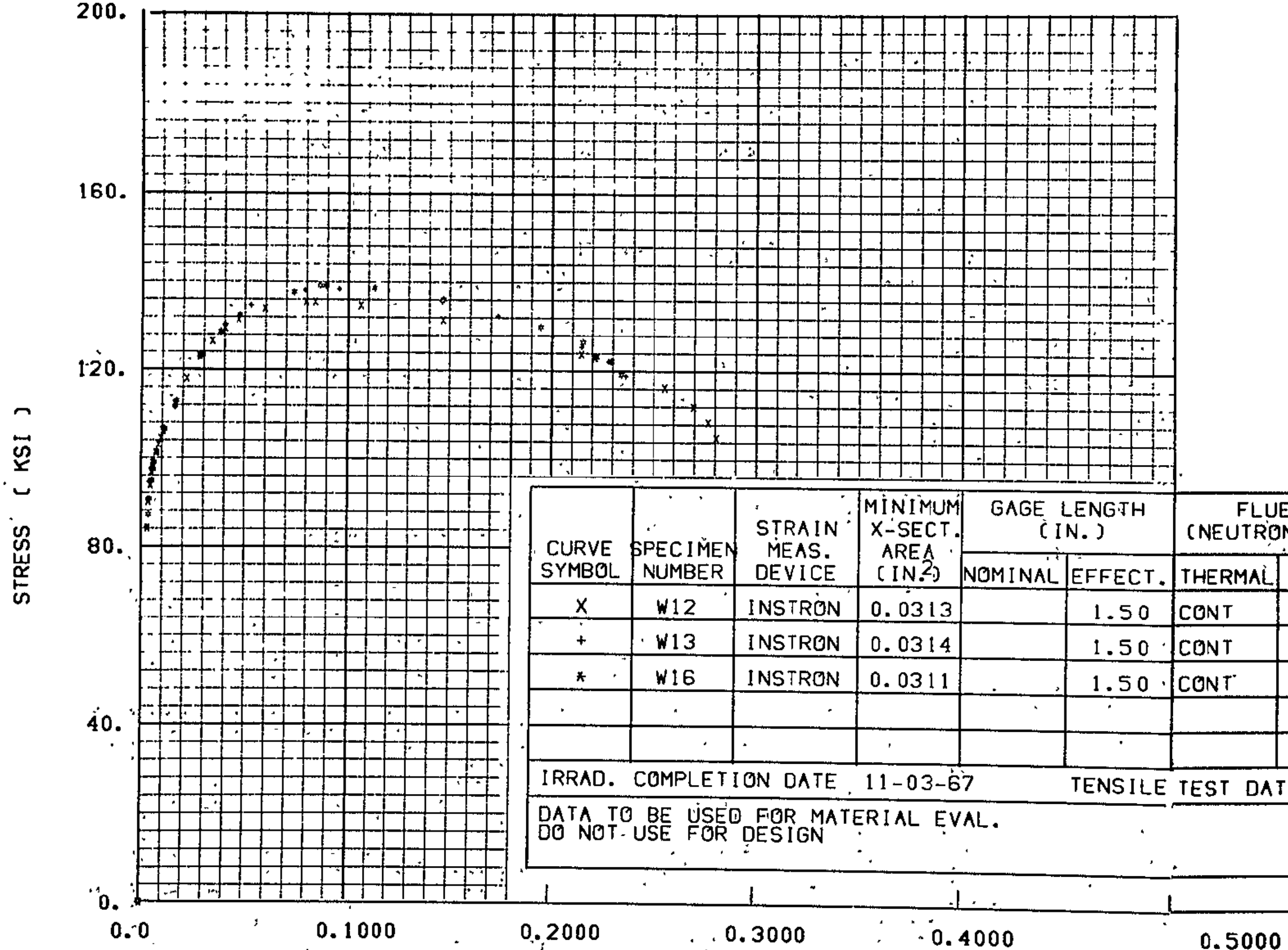
CURVE SYMBOL	SPECIMEN NUMBER	STRAIN MEAS. DEVICE	MINIMUM X-SECT. AREA (IN.^{2})	GAGE LENGTH (IN.)		FLUENCE (NEUTRONS/CM^2)		GAMMA DOSE (ERGS/GM(C))
				NOMINAL	EFFECT.	THERMAL	FAST	
X	W12	INSTRON	0.0313		1.50	CONT		
+	W13	INSTRON	0.0314		1.50	CONT		
*	W16	INSTRON	0.0311		1.50	CONT		

IRRAD. COMPLETION DATE 11-03-67 TENSILE TEST DATE MAR. 68

DATA TO BE USED FOR MATERIAL EVAL.
DO NOT USE FOR DESIGN

FIGURE 6-23 STRESS-STRAIN CURVES FOR WASPALOY. CONTROLS TESTED AT 1660 R (0.0013 IN./IN./MIN)

NPC 26,854



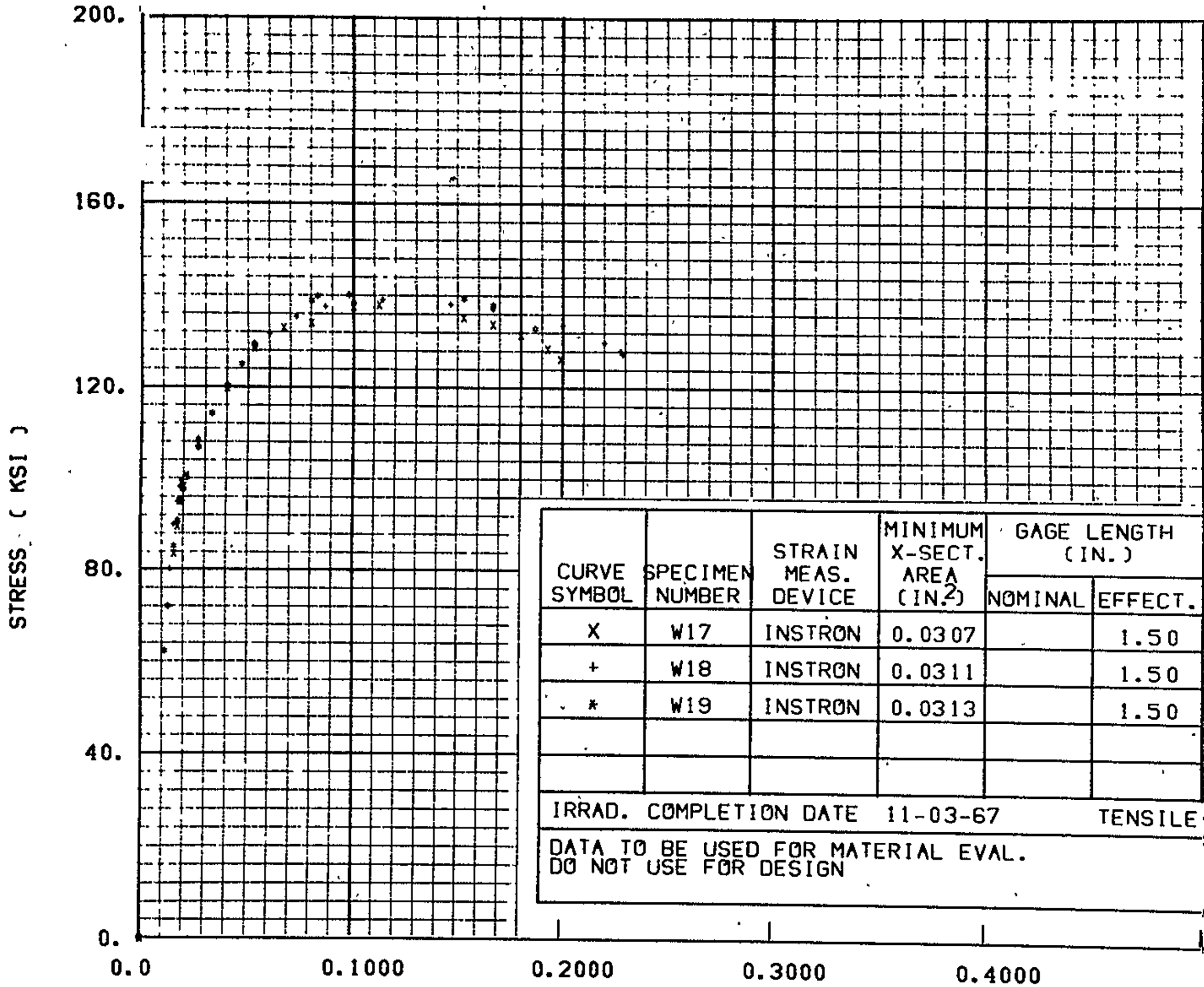
CURVE SYMBOL	SPECIMEN NUMBER	STRAIN MEAS. DEVICE	MINIMUM X-SECT. AREA (IN.^{2})	GAGE LENGTH (IN.) NOMINAL	GAGE LENGTH (IN.) EFFECT.	FLUENCE (NEUTRONS/CM^2) THERMAL	FLUENCE (NEUTRONS/CM^2) FAST	GAMMA DOSE (ERGS/GM(C))
X	W12	INSTRON	0.0313		1.50	CONT		
+	W13	INSTRON	0.0314		1.50	CONT		
*	W16	INSTRON	0.0311		1.50	CONT		

IRRAD. COMPLETION DATE 11-03-67 TENSILE TEST DATE MAR. 68

DATA TO BE USED FOR MATERIAL EVAL.
DO NOT USE FOR DESIGN

FIGURE 6-24 STRESS-STRAIN CURVES FOR WASPALOY. CONTROLS TESTED AT 1660 R (0.0013 IN./IN./MIN). FITTED TO HDBK MOD

NPC 26,855



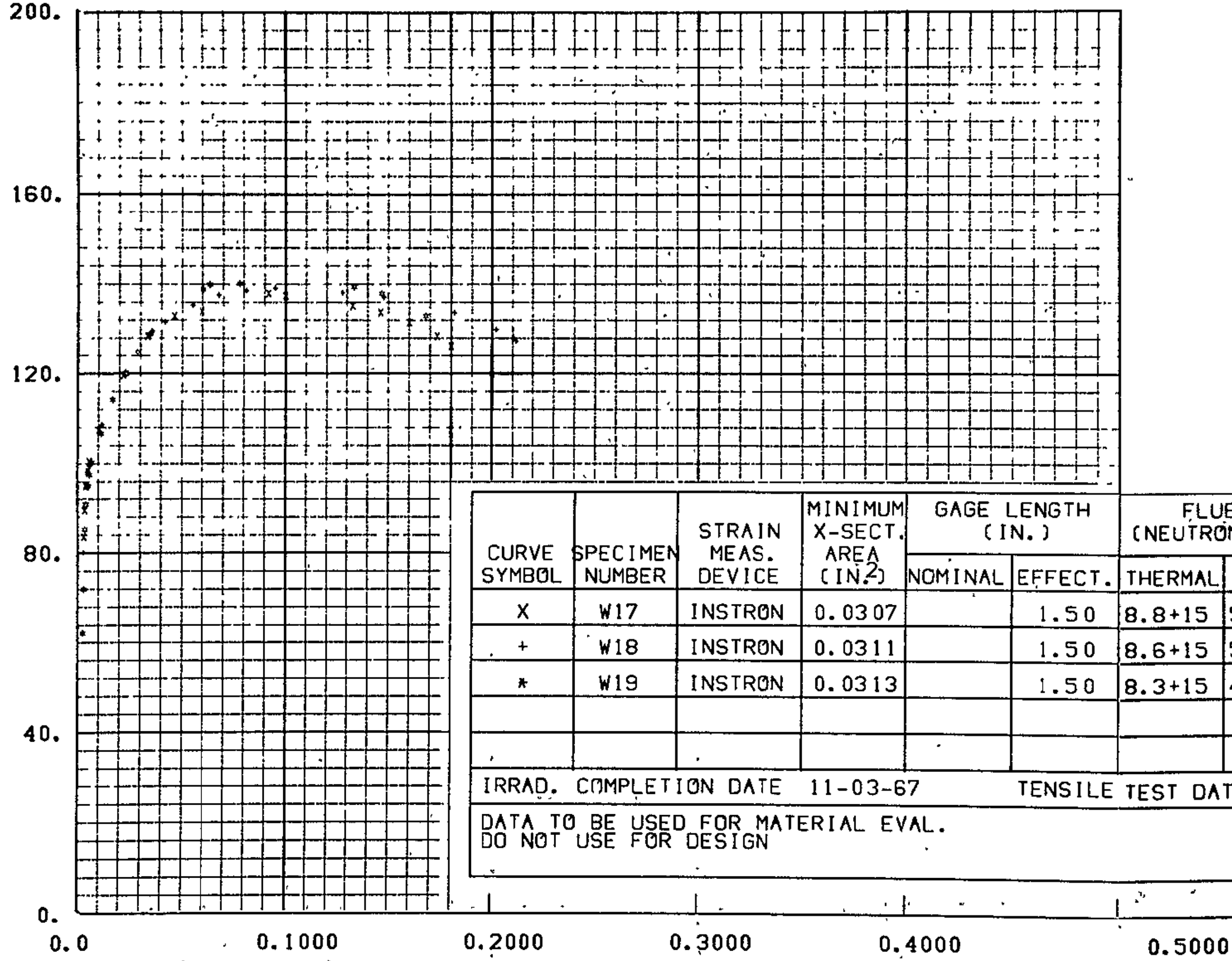
CURVE SYMBOL	SPECIMEN NUMBER	STRAIN MEAS. DEVICE	MINIMUM X-SECT. AREA (IN.^{2})	GAGE LENGTH (IN.)		FLUENCE (NEUTRONS/CM^2)		GAMMA DOSE (ERGS/GM(C))
				NOMINAL	EFFECT.	THERMAL	FAST	
X	W17	INSTRON	0.0307		1.50	8.8+15	5.1+15	2.4+11
+	W18	INSTRON	0.0311		1.50	8.6+15	5.0+15	2.3+11
*	W19	INSTRON	0.0313		1.50	8.3+15	4.7+15	2.3+11

IRRAD. COMPLETION DATE 11-03-67 TENSILE TEST DATE MAR. 68

DATA TO BE USED FOR MATERIAL EVAL.
DO NOT USE FOR DESIGN

STRAIN (IN./IN. OF GAGE LENGTH)(BASED ON CROSSHEAD TRAVEL)

FIGURE 6-25 STRESS-STRAIN CURVES FOR WASPALOY. LOW IRRAD
TESTED AT 1660 R (0.0013 IN./IN./MIN)



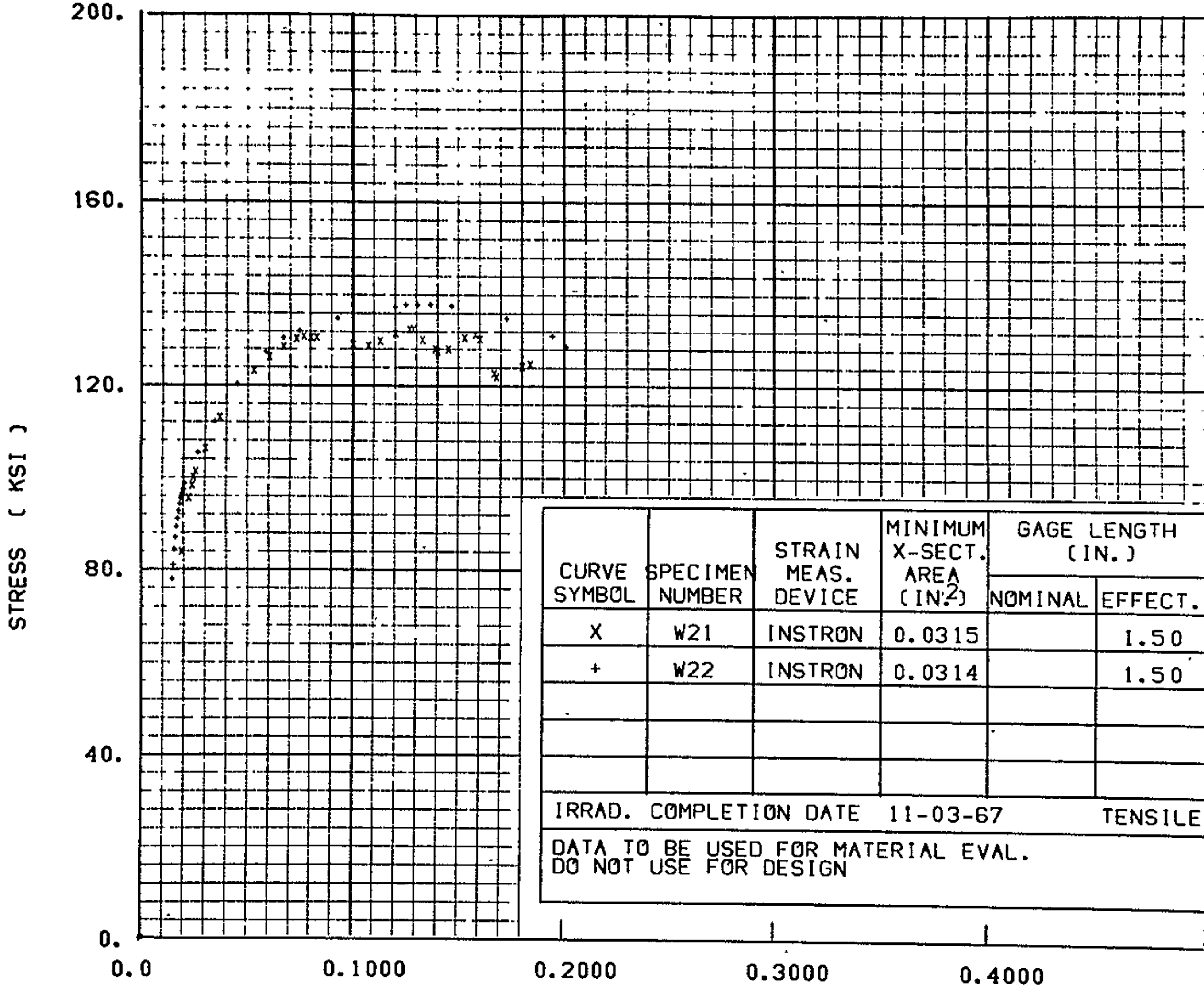
CURVE SYMBOL	SPECIMEN NUMBER	STRAIN MEAS. DEVICE	MINIMUM X-SECT. AREA (IN.^{2})	GAGE LENGTH (IN.) NOMINAL	GAGE LENGTH (IN.) EFFECT.	FLUENCE (NEUTRONS/CM^2) THERMAL	FLUENCE (NEUTRONS/CM^2) FAST	GAMMA DOSE (ERGS/GM(C))
X	W17	INSTRON	0.0307		1.50	8.8+15	5.1+15	2.4+11
+	W18	INSTRON	0.0311		1.50	8.6+15	5.0+15	2.3+11
*	W19	INSTRON	0.0313		1.50	8.3+15	4.7+15	2.3+11

IRRAD. COMPLETION DATE 11-03-67 TENSILE TEST DATE MAR. 68

DATA TO BE USED FOR MATERIAL EVAL.
DO NOT USE FOR DESIGN

FIGURE 6-26 STRESS-STRAIN CURVES FOR WASPALOY. LOW IRRAD TESTED AT 1660 R (0.0013 IN./IN./MIN). FITTED TO HDBK MOD

NPC 26,857



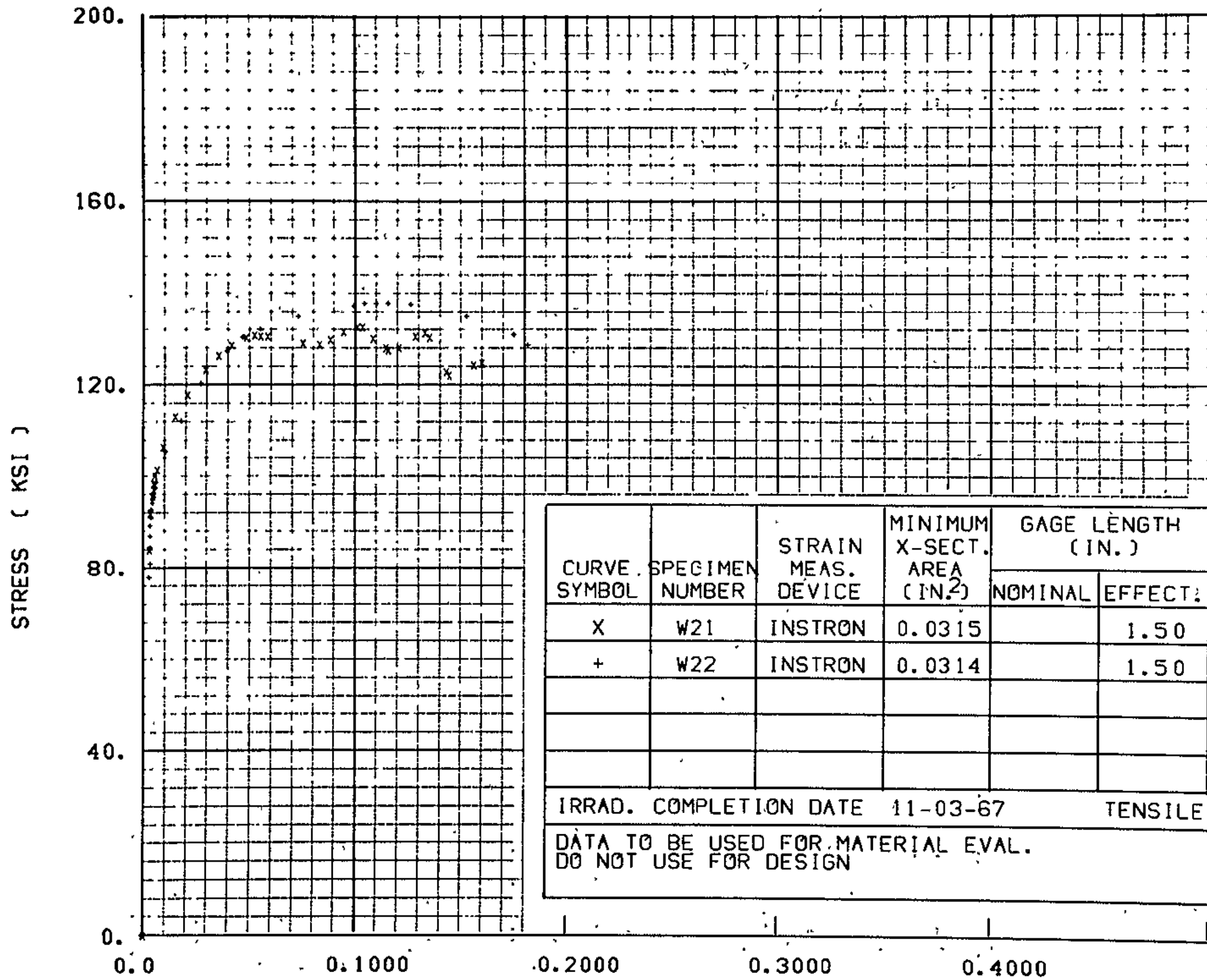
CURVE SYMBOL	SPECIMEN NUMBER	STRAIN MEAS. DEVICE	MINIMUM X-SECT. AREA (IN.^{2})	GAGE LENGTH (IN.) NOMINAL	GAGE LENGTH (IN.) EFFECT.	FLUENCE (NEUTRONS/CM^2) THERMAL	FLUENCE (NEUTRONS/CM^2) FAST	GAMMA DOSE (ERGS/GM(C))
X	W21	INSTRON	0.0315		1.50	2.8+17	1.1+17	1.0+12
+	W22	INSTRON	0.0314		1.50	2.6+17	1.0+17	9.7+11

IRRAD. COMPLETION DATE 11-03-67 TENSILE TEST DATE MAR. 68

DATA TO BE USED FOR MATERIAL EVAL.
DO NOT USE FOR DESIGN

STRAIN (IN./IN. OF GAGE LENGTH)(BASED ON CROSSHEAD TRAVEL)

FIGURE 6-27 STRESS-STRAIN CURVES FOR WASPALOY. MED IRRAD
TESTED AT 1660 R (0.0013 IN./IN./MIN)



CURVE SYMBOL	SPECIMEN NUMBER	STRAIN MEAS. DEVICE	MINIMUM X-SECT. AREA (IN.^{2})	GAGE LENGTH (IN.)		FLUENCE (NEUTRONS/CM^2)		GAMMA DOSE (ERGS/GM(C))
				NOMINAL	EFFECT.	THERMAL	FAST	
X	W21	INSTRON	0.0315		1.50	2.8+17	1.1+17	1.0+12
+	W22	INSTRON	0.0314		1.50	2.6+17	1.0+17	9.7+11

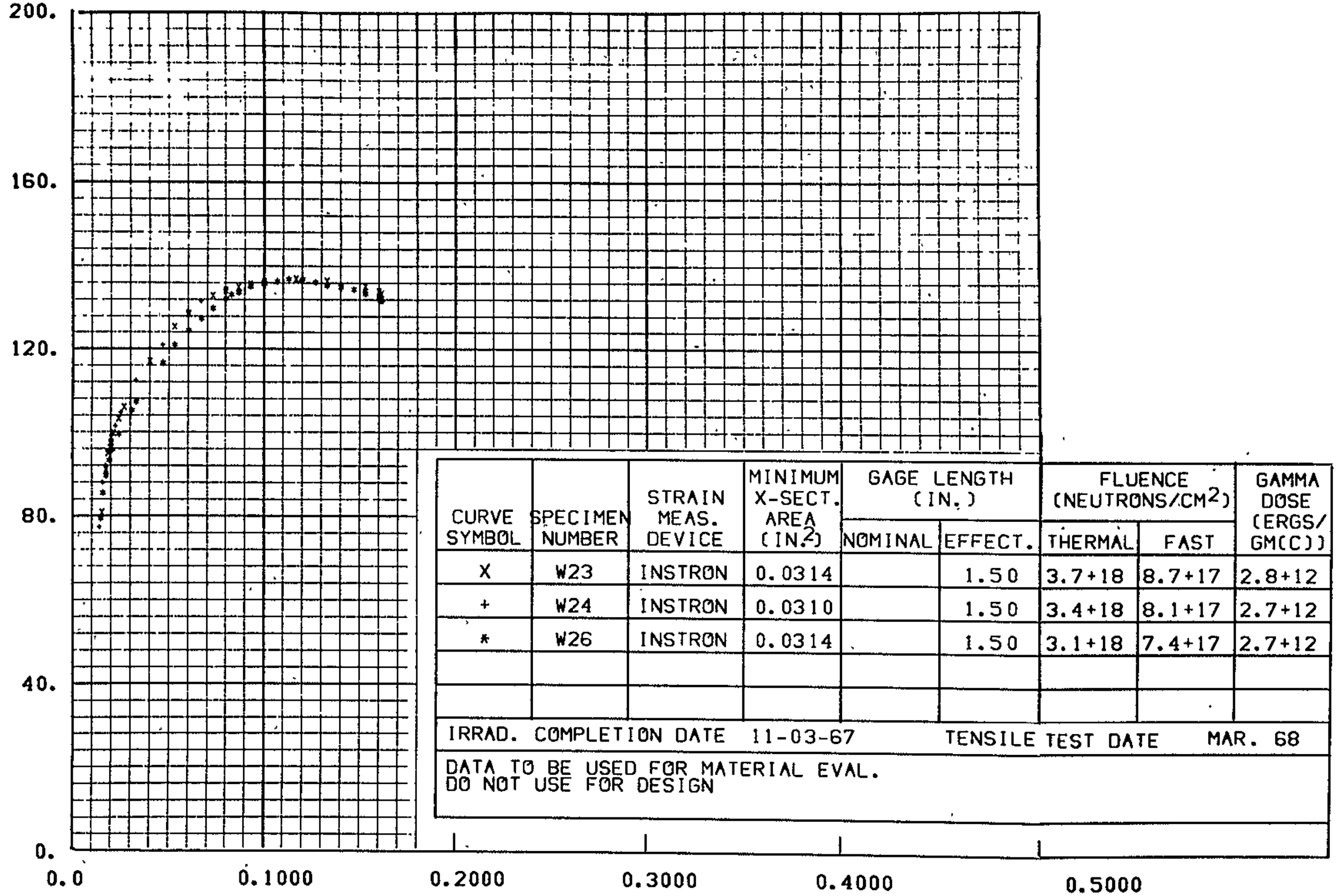
IRRAD. COMPLETION DATE 11-03-67 TENSILE TEST DATE MAR. 68

DATA TO BE USED FOR MATERIAL EVAL.
DO NOT USE FOR DESIGN

STRAIN (IN./IN. OF GAGE LENGTH)(BASED ON HANDBOOK MODULUS)

FIGURE 6-28 STRESS-STRAIN CURVES FOR WASPALOY. MED IRRAD
TESTED AT 1660 R (0.0013 IN./IN./MIN). FITTED TO HDBK MOD

NPC 26,859



CURVE SYMBOL	SPECIMEN NUMBER	STRAIN MEAS. DEVICE	MINIMUM X-SECT. AREA (IN.^{2})	GAGE LENGTH (IN.) NOMINAL	GAGE LENGTH (IN.) EFFECT.	FLUENCE (NEUTRONS/CM^2) THERMAL	FLUENCE (NEUTRONS/CM^2) FAST	GAMMA DOSE (ERGS/GM(C))
X	W23	INSTRON	0.0314		1.50	3.7+18	8.7+17	2.8+12
+	W24	INSTRON	0.0310		1.50	3.4+18	8.1+17	2.7+12
*	W26	INSTRON	0.0314		1.50	3.1+18	7.4+17	2.7+12

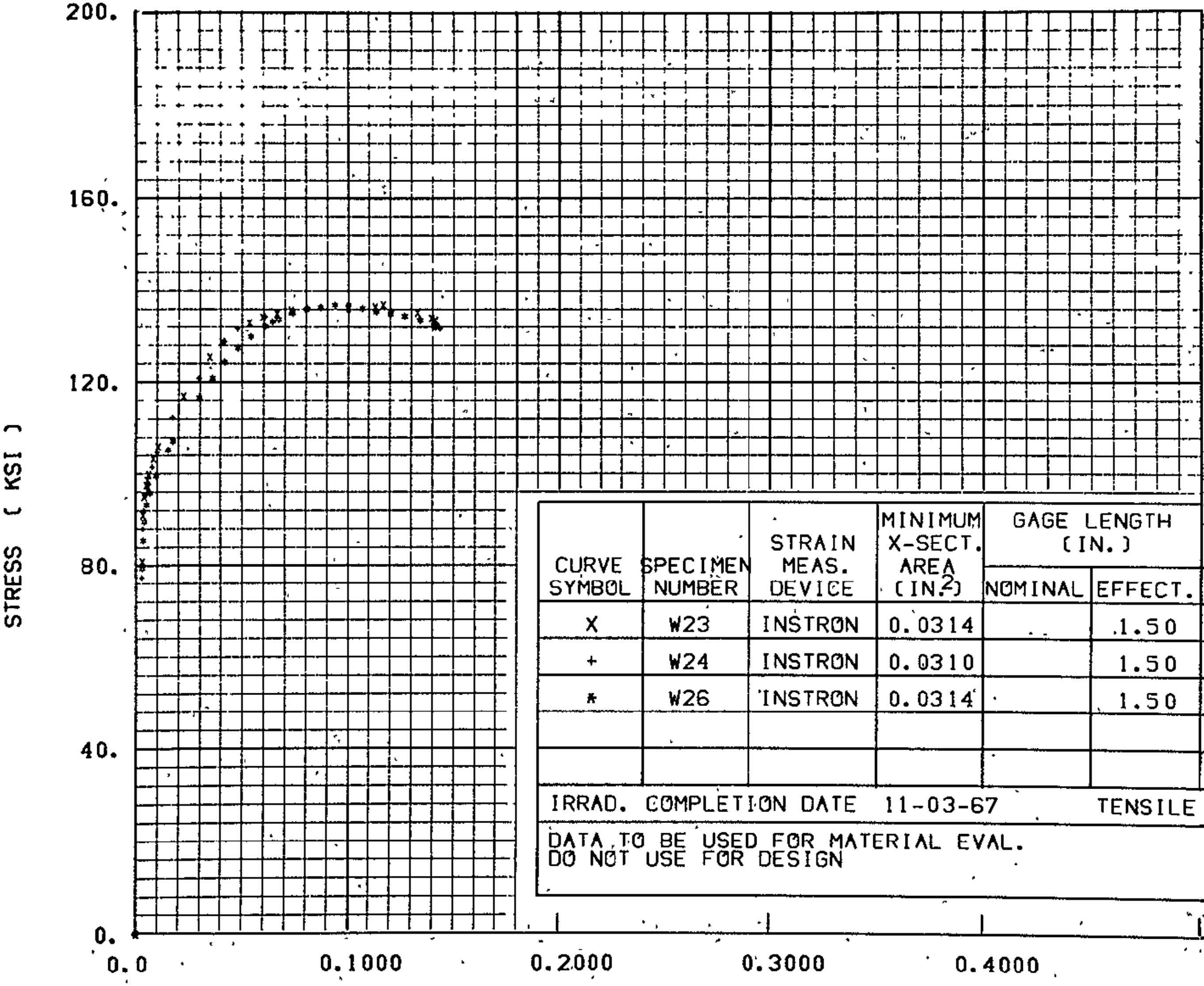
IRRAD. COMPLETION DATE 11-03-67 TENSILE TEST DATE MAR. 68

DATA TO BE USED FOR MATERIAL EVAL.
DO NOT USE FOR DESIGN

STRAIN (IN./IN. OF GAGE LENGTH)(BASED ON CROSSHEAD TRAVEL)

FIGURE 6-29 STRESS-STRAIN CURVES FOR WASPALOY. HIGH IRRAD
TESTED AT 1660 R (0.0013 IN./IN./MIN)

NPC 26,860



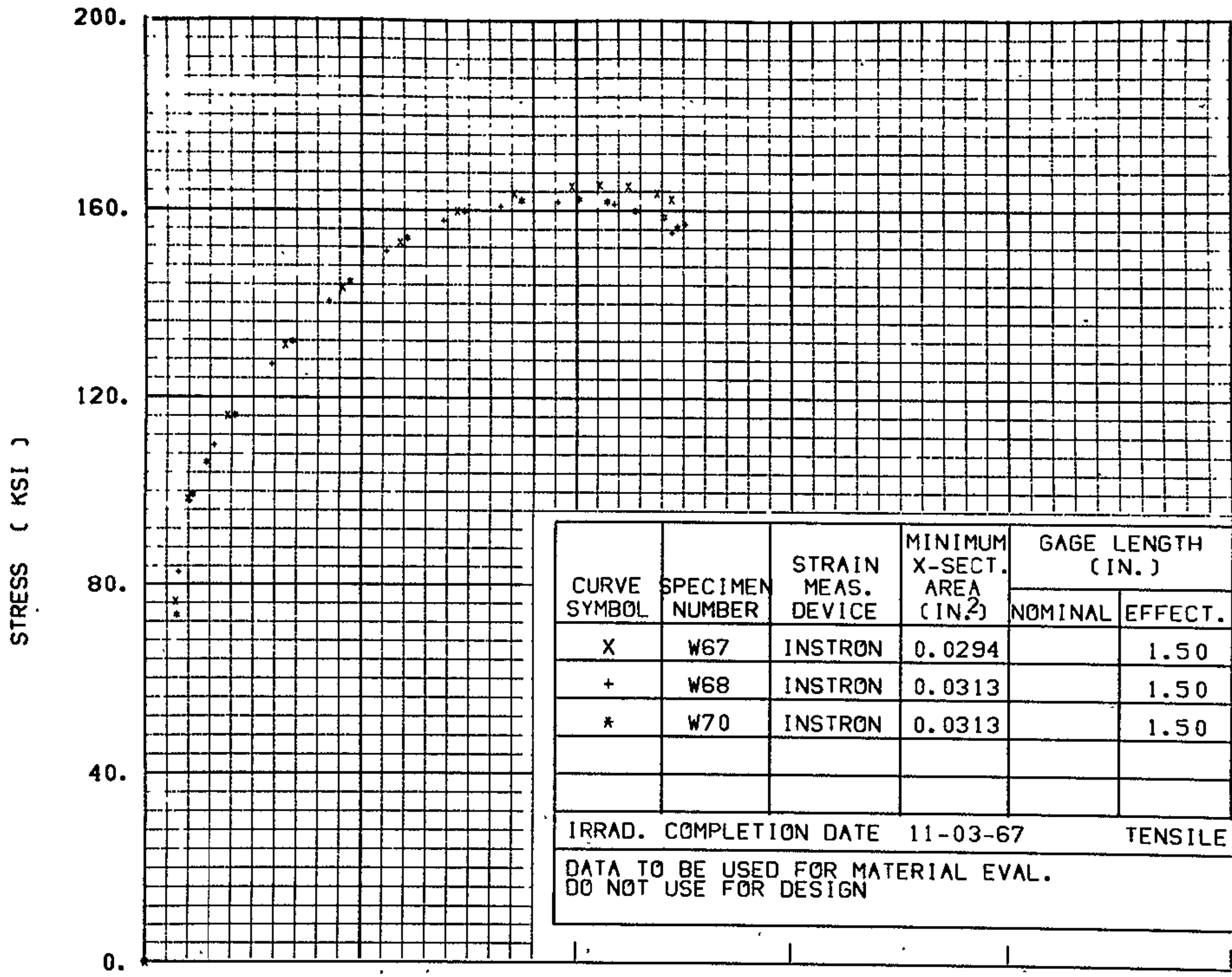
CURVE SYMBOL	SPECIMEN NUMBER	STRAIN MEAS. DEVICE	MINIMUM X-SECT. AREA (IN.^{2})	GAGE LENGTH (IN.) NOMINAL	GAGE LENGTH (IN.) EFFECT.	FLUENCE (NEUTRONS/CM^2) THERMAL	FLUENCE (NEUTRONS/CM^2) FAST	GAMMA DOSE (ERGS/GM(C))
X	W23	INSTRON	0.0314		1.50	3.7+18	8.7+17	2.8+12
+	W24	INSTRON	0.0310		1.50	3.4+18	8.1+17	2.7+12
*	W26	INSTRON	0.0314		1.50	3.1+18	7.4+17	2.7+12

IRRAD. COMPLETION DATE 11-03-67 TENSILE TEST DATE MAR. 68

DATA TO BE USED FOR MATERIAL EVAL.
DO NOT USE FOR DESIGN

FIGURE 6-30 STRESS-STRAIN CURVES FOR WASPALOY. HIGH IRRAD
TESTED AT 1660 R (0.0013 IN./IN./MIN), FITTED TO HDBK MOD

NPC 26,861



CURVE SYMBOL	SPECIMEN NUMBER	STRAIN MEAS. DEVICE	MINIMUM X-SECT. AREA (IN.^{2})	GAGE LENGTH (IN.) NOMINAL	GAGE LENGTH (IN.) EFFECT.	FLUENCE (NEUTRONS/CM^2) THERMAL	FLUENCE (NEUTRONS/CM^2) FAST	GAMMA DOSE (ERGS/GM(C))
X	W67	INSTRON	0.0294		1.50	CONT		
+	W68	INSTRON	0.0313		1.50	CONT		
*	W70	INSTRON	0.0313		1.50	CONT		

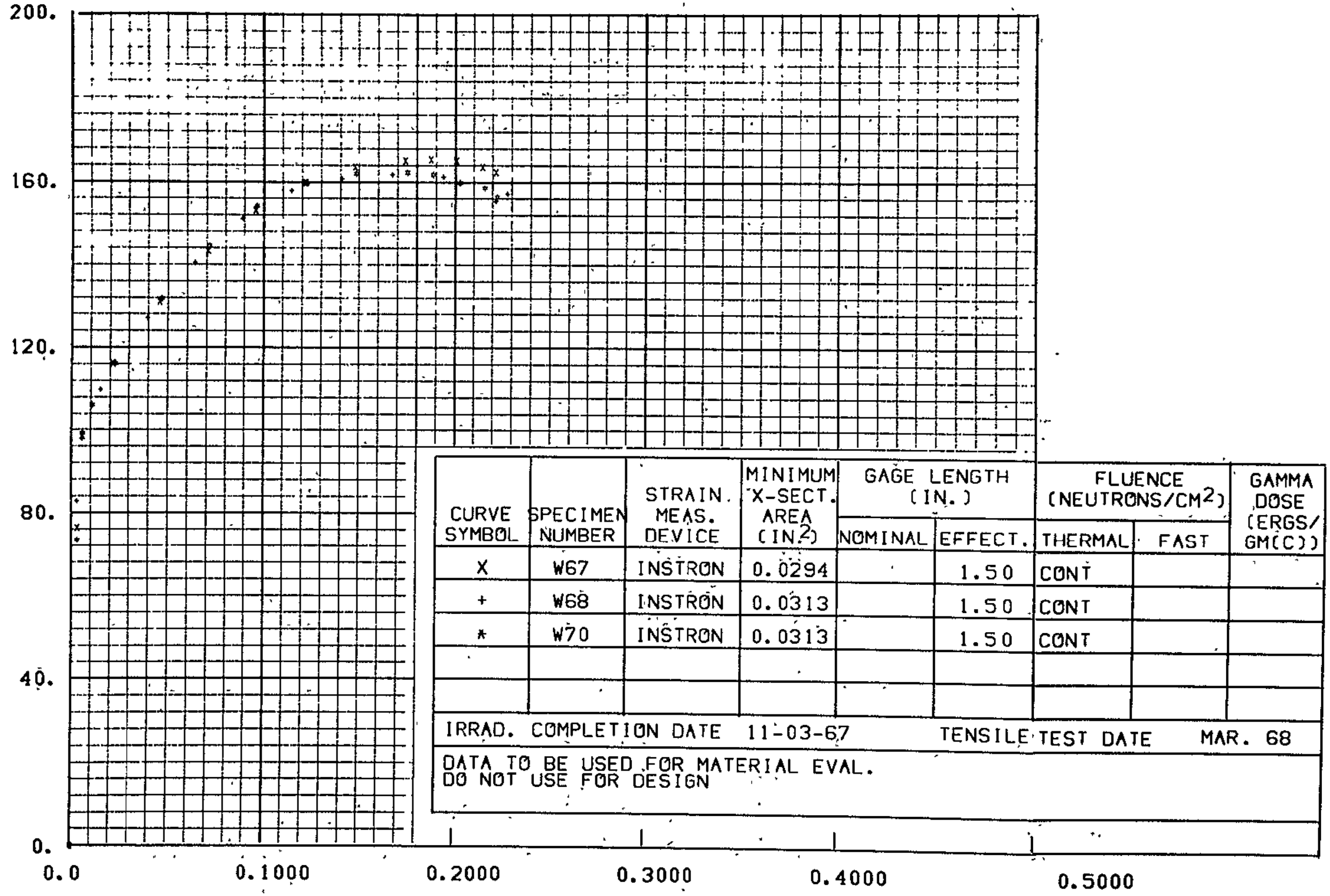
IRRAD. COMPLETION DATE 11-03-67 TENSILE TEST DATE MAR. 68

DATA TO BE USED FOR MATERIAL EVAL.
DO NOT USE FOR DESIGN

STRAIN (IN./IN. OF GAGE LENGTH)(BASED ON CROSSHEAD TRAVEL)

FIGURE 6-31 STRESS-STRAIN CURVES FOR WASPALOY. CONTROLS TESTED AT 1660 R (0.13 IN./IN./MIN)

NPC 26,862



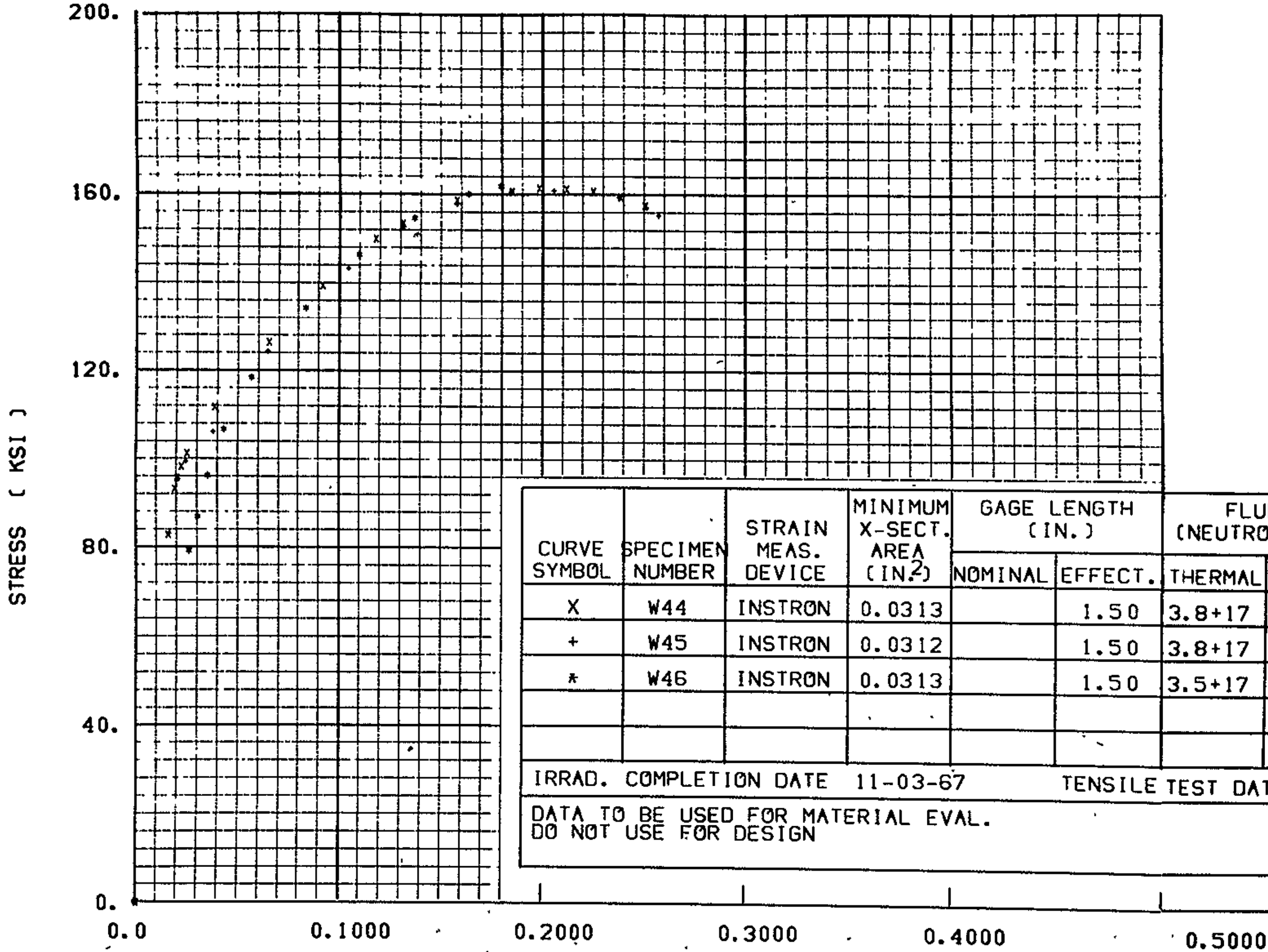
CURVE SYMBOL	SPECIMEN NUMBER	STRAIN. MEAS. DEVICE	MINIMUM X-SECT. AREA (IN.2)	GAGE LENGTH (IN.) NOMINAL	GAGE LENGTH (IN.) EFFECT.	FLUENCE (NEUTRONS/CM2) THERMAL	FLUENCE (NEUTRONS/CM2) FAST	GAMMA DOSE (ERGS/GM(C))
X	W67	INSTRON	0.0294		1.50	CONT		
+	W68	INSTRON	0.0313		1.50	CONT		
*	W70	INSTRON	0.0313		1.50	CONT		

IRRAD. COMPLETION DATE 11-03-67 TENSILE TEST DATE MAR. 68

DATA TO BE USED FOR MATERIAL EVAL.
DO NOT USE FOR DESIGN

FIGURE 6-32 STRESS-STRAIN CURVES FOR WASPALOY. CONTROLS TESTED AT 1660 R (0.13 IN./IN./MIN). FITTED TO HDBK MOD

NPC 26,863



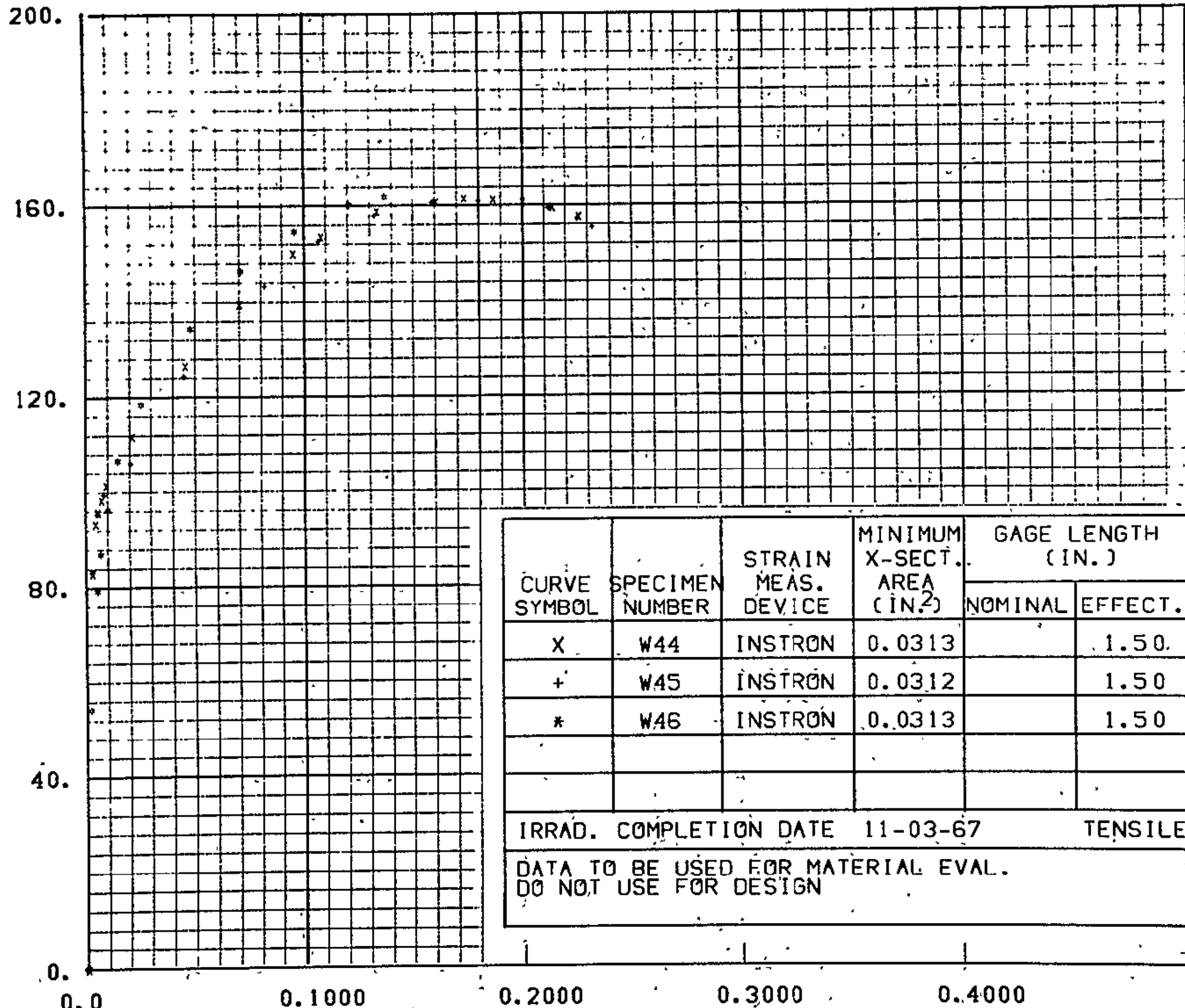
CURVE SYMBOL	SPECIMEN NUMBER	STRAIN MEAS. DEVICE	MINIMUM X-SECT. AREA ($IN.^2$)	GAGE LENGTH (IN.) NOMINAL	GAGE LENGTH (IN.) EFFECT.	FLUENCE ($NEUTRONS/CM^2$) THERMAL	FLUENCE ($NEUTRONS/CM^2$) FAST	GAMMA DOSE (ERGS/ GM(C))
X	W44	INSTRON	0.0313		1.50	3.8+17	1.4+17	1.1+12
+	W45	INSTRON	0.0312		1.50	3.8+17	1.4+17	1.2+12
*	W46	INSTRON	0.0313		1.50	3.5+17	1.2+17	1.2+12

IRRAD. COMPLETION DATE 11-03-67 TENSILE TEST DATE MAR. 68

DATA TO BE USED FOR MATERIAL EVAL.
DO NOT USE FOR DESIGN

STRAIN (IN./IN. OF GAGE LENGTH)(BASED ON CROSSHEAD TRAVEL)

FIGURE 6-33 STRESS-STRAIN CURVES FOR WASPALOY. MED IRRAD
TESTED AT 1660 R (0.13 IN./IN./MIN)



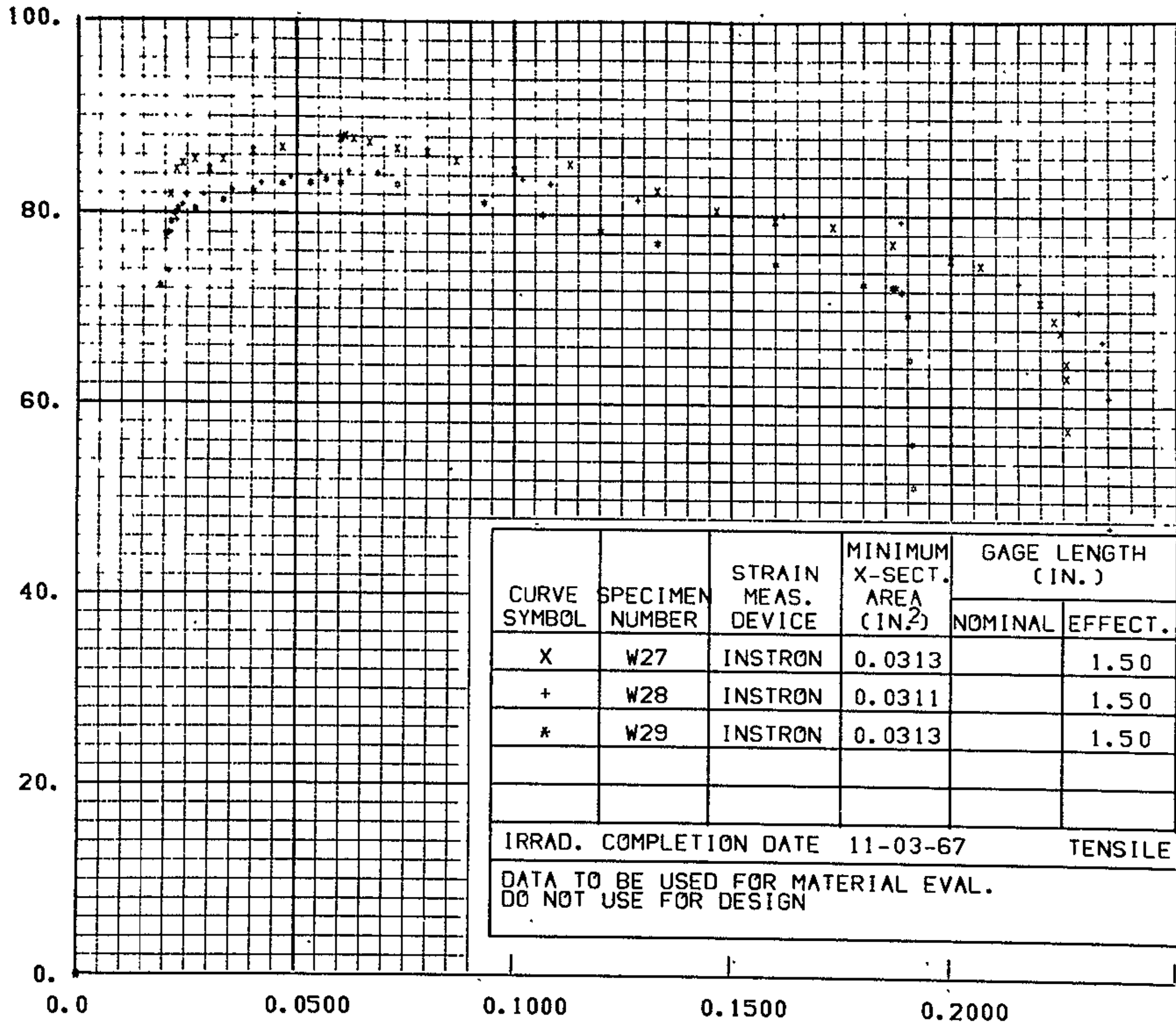
CURVE SYMBOL	SPECIMEN NUMBER	STRAIN MEAS. DEVICE	MINIMUM X-SECT. AREA (IN.2)	GAGE LENGTH (IN.)		FLUENCE (NEUTRONS/CM2)		GAMMA DOSE (ERGS/GM(C))
				NOMINAL	EFFECT.	THERMAL	FAST	
X	W44	INSTRON	0.0313		1.50	3.8+17	1.4+17	1.1+12
+	W45	INSTRON	0.0312		1.50	3.8+17	1.4+17	1.2+12
*	W46	INSTRON	0.0313		1.50	3.5+17	1.2+17	1.2+12

IRRAD. COMPLETION DATE 11-03-67 TENSILE TEST DATE MAR. 68

DATA TO BE USED FOR MATERIAL EVAL.
DO NOT USE FOR DESIGN

FIGURE 6-34 STRESS-STRAIN CURVES FOR WASPALOY. MED IRRAD
TESTED AT 1660 R (0.13 IN./IN./MIN), FITTED TO HDBK MOD

NPC 26,865



CURVE SYMBOL	SPECIMEN NUMBER	STRAIN MEAS. DEVICE	MINIMUM X-SECT. AREA (IN.^{2})	GAGE LENGTH (IN.) NOMINAL	GAGE LENGTH (IN.) EFFECT.	FLUENCE (NEUTRONS/CM^2) THERMAL	FLUENCE (NEUTRONS/CM^2) FAST	GAMMA DOSE (ERGS/GM(C))
X	W27	INSTRON	0.0313		1.50	CONT		
+	W28	INSTRON	0.0311		1.50	CONT		
*	W29	INSTRON	0.0313		1.50	CONT		

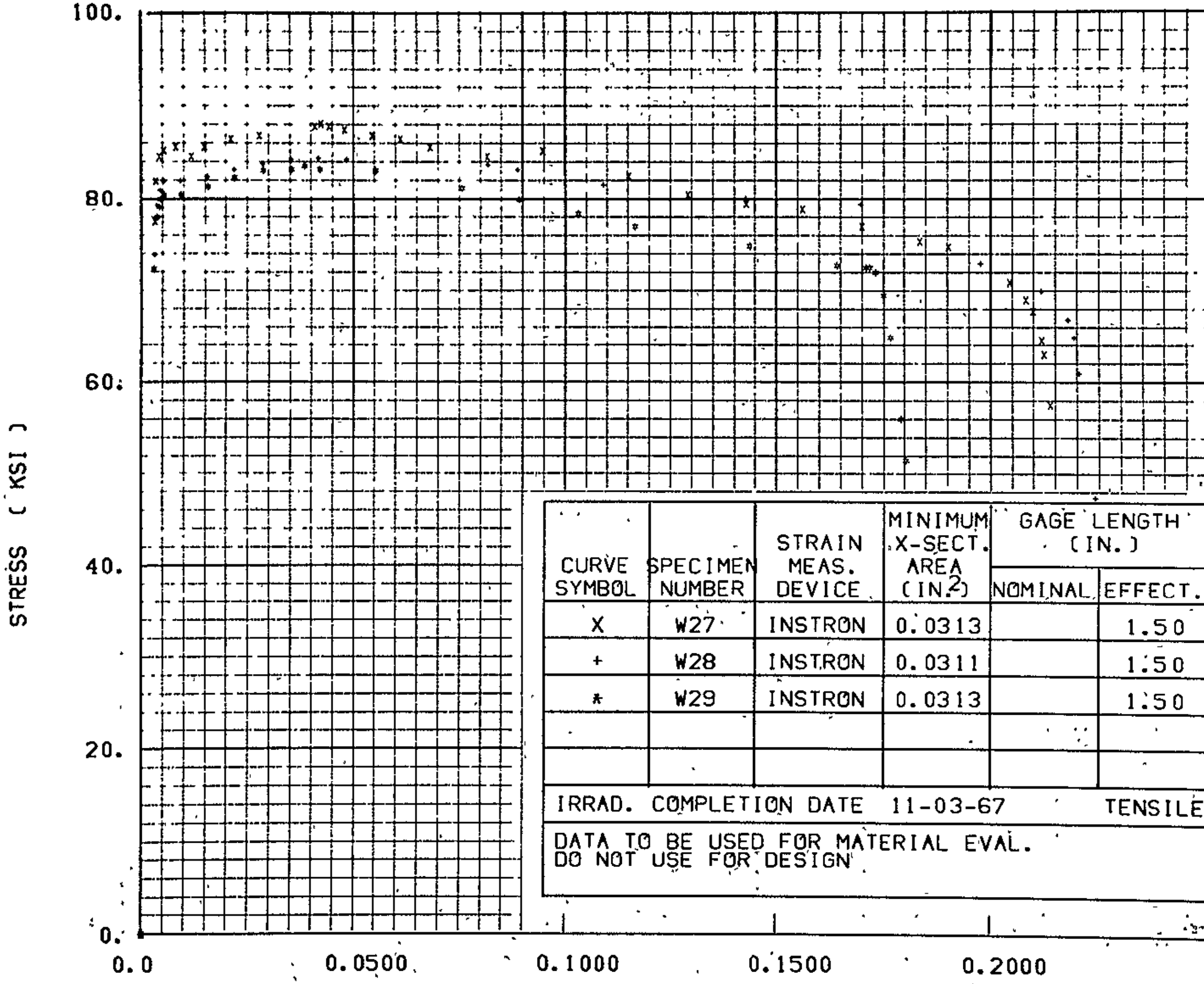
IRRAD. COMPLETION DATE 11-03-67 TENSILE TEST DATE MAR. 68

DATA TO BE USED FOR MATERIAL EVAL.
DO NOT USE FOR DESIGN

STRAIN (IN./IN. OF GAGE LENGTH)(BASED ON CROSSHEAD TRAVEL)

FIGURE 6-35 STRESS-STRAIN CURVES FOR WASPALOY. CONTROLS TESTED AT 1860 R (0.0013 IN./IN./MIN)

NPC 26,866



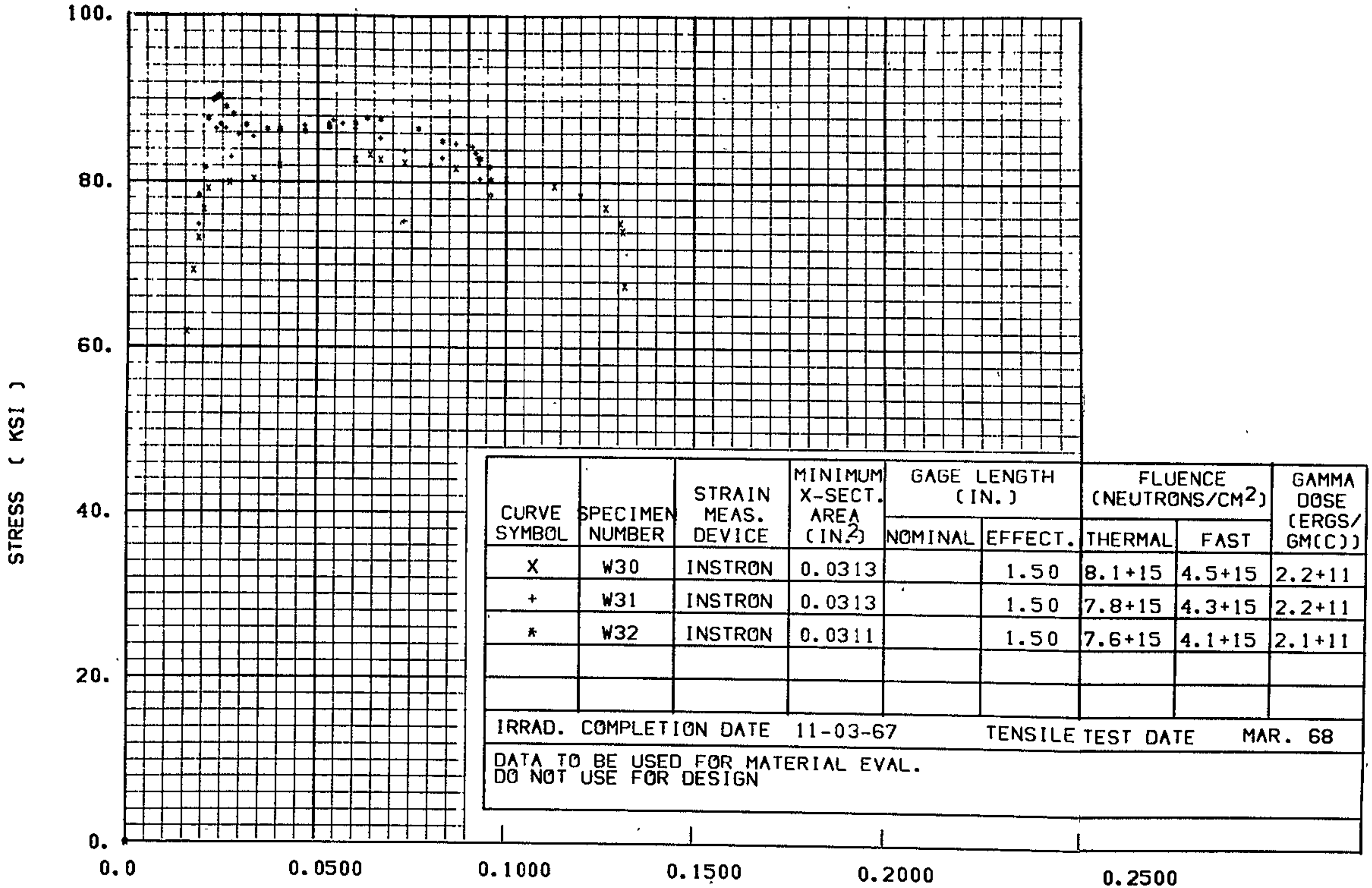
CURVE SYMBOL	SPECIMEN NUMBER	STRAIN MEAS. DEVICE	MINIMUM X-SECT. AREA (IN.^{2})	GAGE LENGTH (IN.)		FLUENCE (NEUTRONS/CM^2)		GAMMA DOSE (ERGS/GM(C))
				NOMINAL	EFFECT.	THERMAL	FAST	
X	W27	INSTRON	0.0313		1.50	CONT		
+	W28	INSTRON	0.0311		1.50	CONT		
*	W29	INSTRON	0.0313		1.50	CONT		

IRRAD. COMPLETION DATE 11-03-67 TENSILE TEST DATE MAR. 68

DATA TO BE USED FOR MATERIAL EVAL.
DO NOT USE FOR DESIGN

STRAIN (IN./IN. OF GAGE LENGTH)(BASED ON HANDBOOK MODULUS)

FIGURE 6-36 STRESS-STRAIN CURVES FOR WASPALOY. CONTROLS TESTED AT 1860 R (0.0013 IN./IN./MIN). FITTED TO HDBK MOD

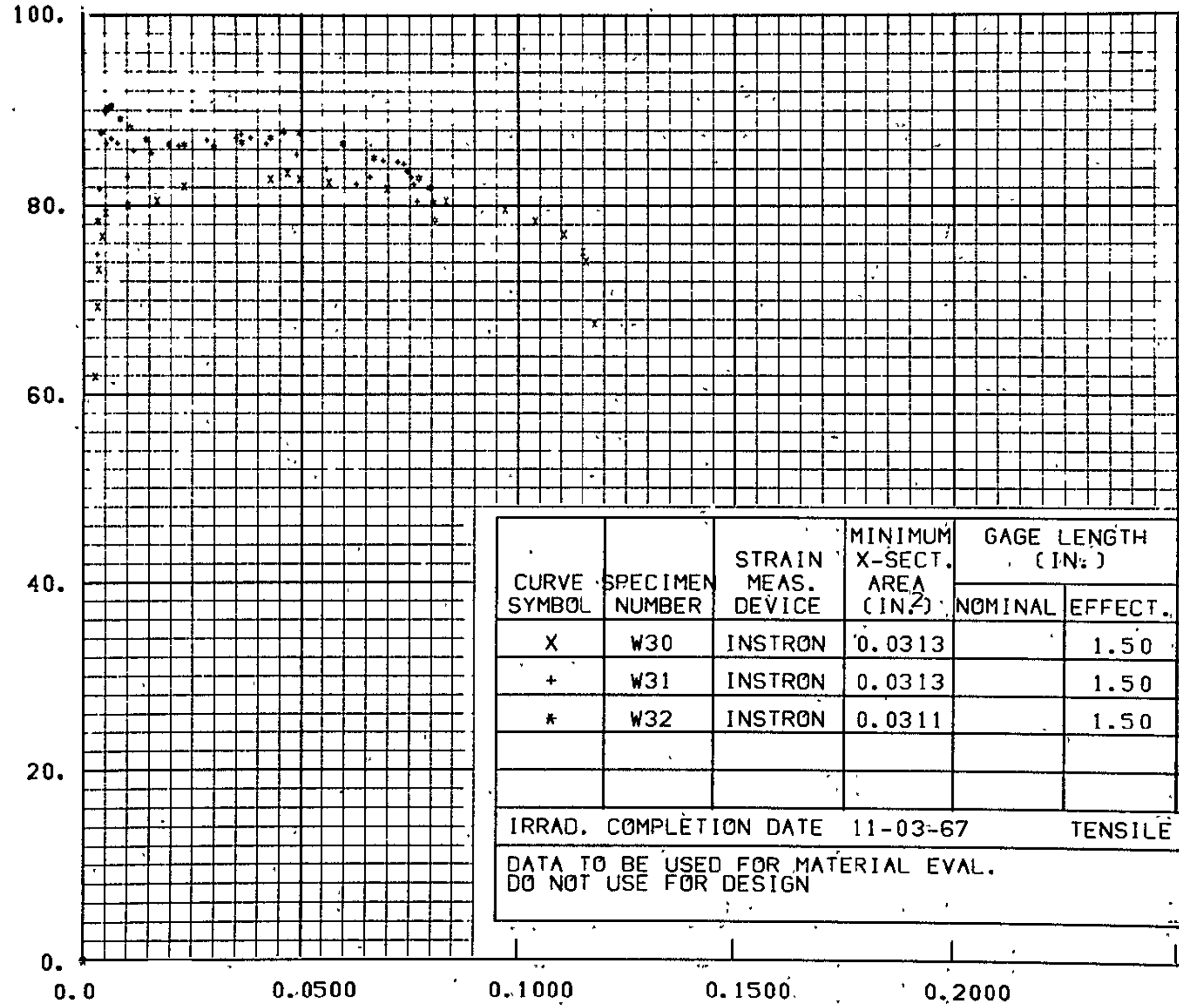


CURVE SYMBOL	SPECIMEN NUMBER	STRAIN MEAS. DEVICE	MINIMUM X-SECT. AREA (IN.^{2})	GAGE LENGTH (IN.)		FLUENCE (NEUTRONS/CM^2)		GAMMA DOSE (ERGS/GM(C))
				NOMINAL	EFFECT.	THERMAL	FAST	
X	W30	INSTRON	0.0313		1.50	8.1+15	4.5+15	2.2+11
+	W31	INSTRON	0.0313		1.50	7.8+15	4.3+15	2.2+11
*	W32	INSTRON	0.0311		1.50	7.6+15	4.1+15	2.1+11

IRRAD. COMPLETION DATE 11-03-67 TENSILE TEST DATE MAR. 68

DATA TO BE USED FOR MATERIAL EVAL.
DO NOT USE FOR DESIGN

FIGURE 6-37 STRESS-STRAIN CURVES FOR WASPALOY. LOW IRRAD
TESTED AT 1860 R (0.0013 IN./IN./MIN)



CURVE SYMBOL	SPECIMEN NUMBER	STRAIN MEAS. DEVICE	MINIMUM X-SECT. AREA (IN.^{2})	GAGE LENGTH (IN.) NOMINAL	GAGE LENGTH (IN.) EFFECT.	FLUENCE (NEUTRONS/CM^2) THERMAL	FLUENCE (NEUTRONS/CM^2) FAST	GAMMA DOSE (ERGS/GM(C))
X	W30	INSTRON	0.0313		1.50	8.1+15	4.5+15	2.2+11
+	W31	INSTRON	0.0313		1.50	7.8+15	4.3+15	2.2+11
*	W32	INSTRON	0.0311		1.50	7.6+15	4.1+15	2.1+11

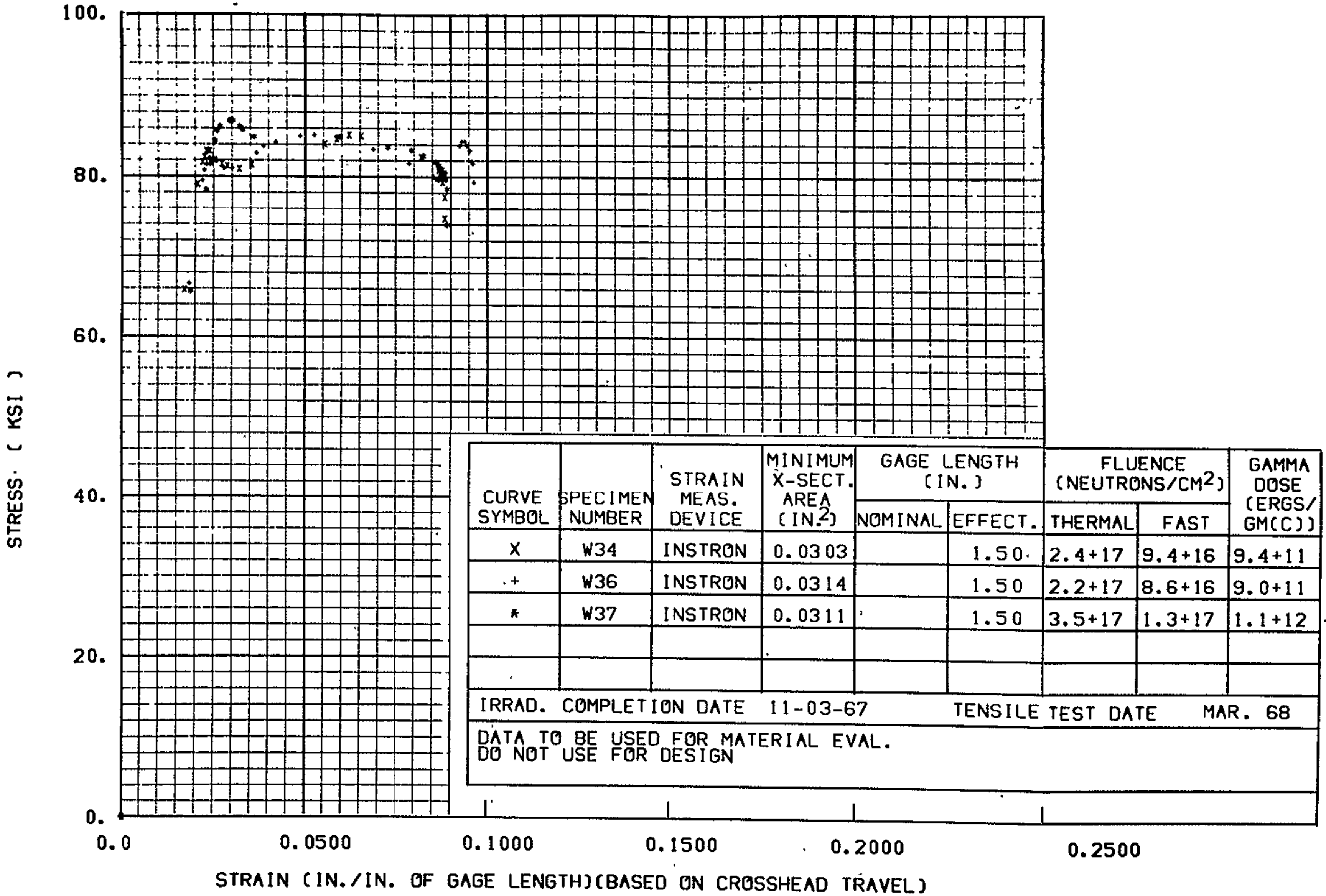
IRRAD. COMPLETION DATE 11-03-67 TENSILE TEST DATE MAR. 68

DATA TO BE USED FOR MATERIAL EVAL.
DO NOT USE FOR DESIGN

STRAIN (IN./IN. OF GAGE LENGTH)(BASED ON HANDBOOK MODULUS)

FIGURE 6-38 STRESS-STRAIN CURVES FOR WASPALOY. LOW IRRAD
TESTED AT 1860 R (0.0013 IN./IN./MIN). FITTED TO HDBK MOD

NPC 26,869

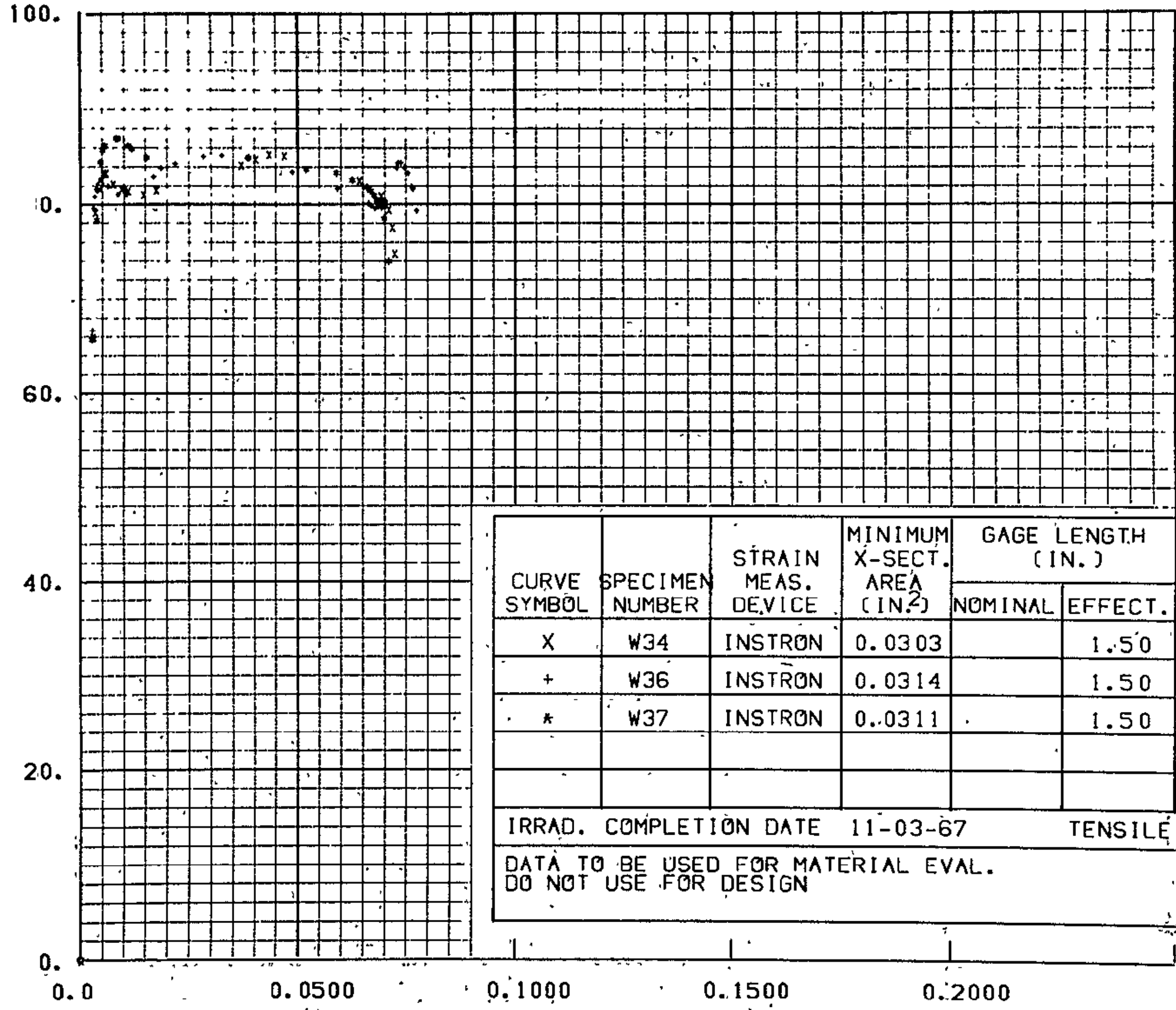


CURVE SYMBOL	SPECIMEN NUMBER	STRAIN MEAS. DEVICE	MINIMUM X-SECT. AREA (IN.^{2})	GAGE LENGTH (IN.)		FLUENCE (NEUTRONS/CM^2)		GAMMA DOSE (ERGS/GM(C))
				NOMINAL	EFFECT.	THERMAL	FAST	
X	W34	INSTRON	0.0303		1.50	2.4+17	9.4+16	9.4+11
+	W36	INSTRON	0.0314		1.50	2.2+17	8.6+16	9.0+11
*	W37	INSTRON	0.0311		1.50	3.5+17	1.3+17	1.1+12

IRRAD. COMPLETION DATE 11-03-67 TENSILE TEST DATE MAR. 68

DATA TO BE USED FOR MATERIAL EVAL.
DO NOT USE FOR DESIGN

FIGURE 6-39 STRESS-STRAIN CURVES FOR WASPALOY. MED IRRAD
TESTED AT 1860 R (0.0013 IN./IN./MIN)



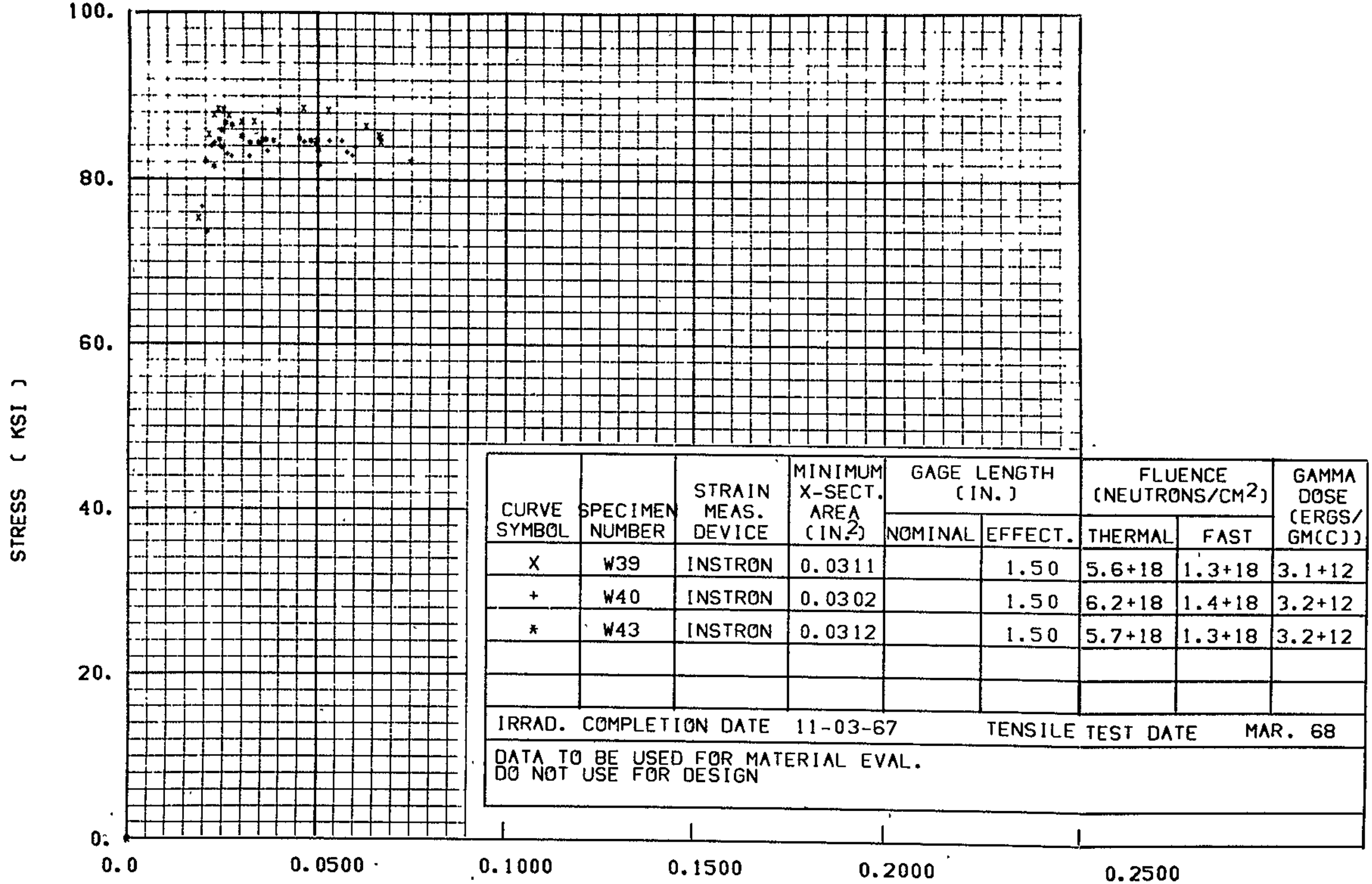
CURVE SYMBOL	SPECIMEN NUMBER	STRAIN MEAS. DEVICE	MINIMUM X-SECT. AREA (IN.^{2})	GAGE LENGTH (IN.)		FLUENCE (NEUTRONS/CM^2)		GAMMA DOSE (ERGS/GM(C))
				NOMINAL	EFFECT.	THERMAL	FAST	
X	W34	INSTRON	0.0303		1.50	2.4+17	9.4+16	9.4+11
+	W36	INSTRON	0.0314		1.50	2.2+17	8.6+16	9.0+11
*	W37	INSTRON	0.0311		1.50	3.5+17	1.3+17	1.1+12

IRRAD. COMPLETION DATE 11-03-67 TENSILE TEST DATE MAR. 68

DATA TO BE USED FOR MATERIAL EVAL.
DO NOT USE FOR DESIGN

STRAIN (IN./IN. OF GAGE LENGTH)(BASED ON HANDBOOK MODULUS)

FIGURE 6-40 STRESS-STRAIN CURVES FOR WASPALOY. MED IRRAD
TESTED AT 1860 R (0.0013 IN./IN./MIN). FITTED TO HDBK MOD



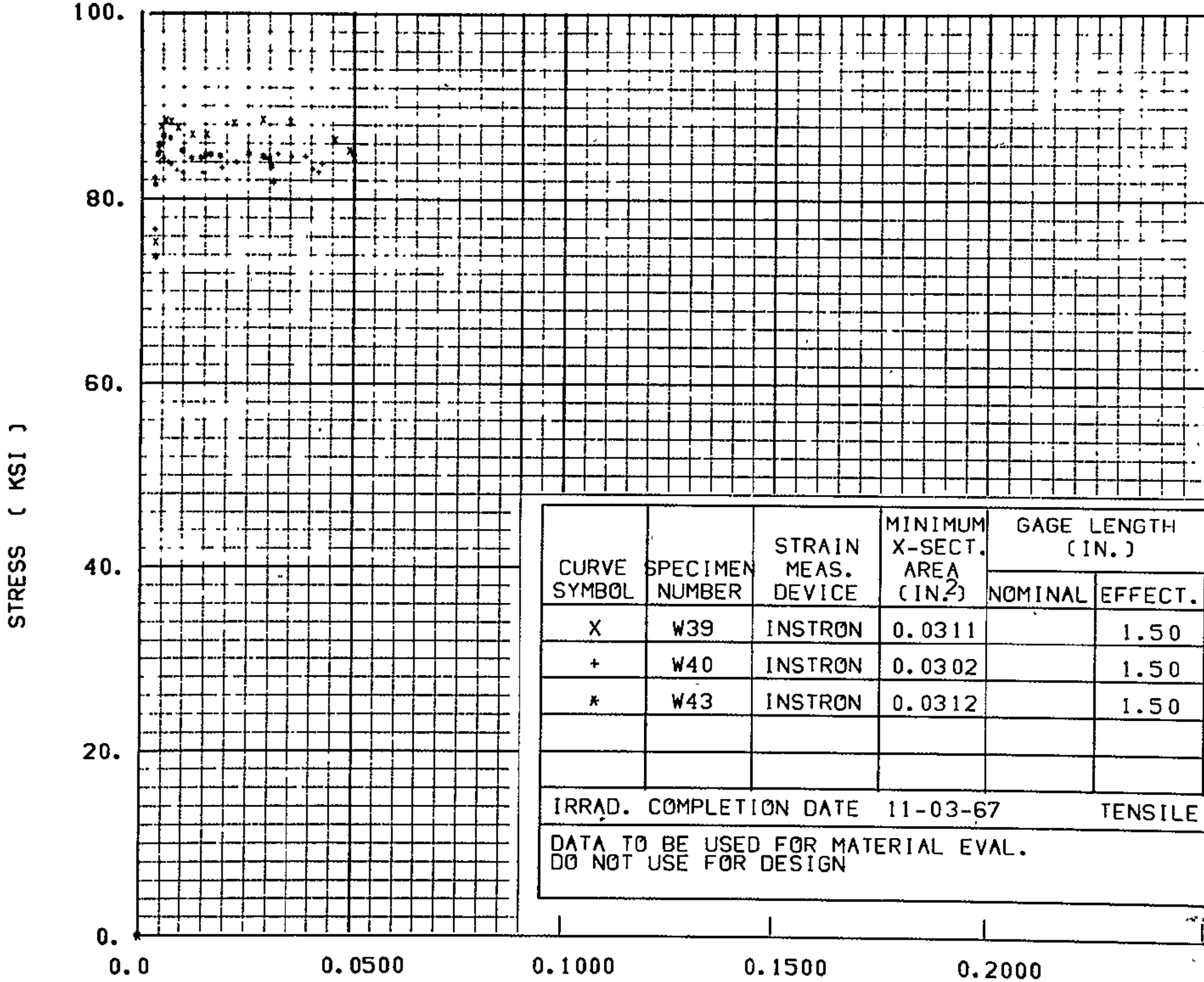
CURVE SYMBOL	SPECIMEN NUMBER	STRAIN MEAS. DEVICE	MINIMUM X-SECT. AREA (IN.^{2})	GAGE LENGTH (IN.) NOMINAL	GAGE LENGTH (IN.) EFFECT.	FLUENCE (NEUTRONS/CM^2) THERMAL	FLUENCE (NEUTRONS/CM^2) FAST	GAMMA DOSE (ERGS/GM(C))
X	W39	INSTRON	0.0311		1.50	5.6+18	1.3+18	3.1+12
+	W40	INSTRON	0.0302		1.50	6.2+18	1.4+18	3.2+12
*	W43	INSTRON	0.0312		1.50	5.7+18	1.3+18	3.2+12

IRRAD. COMPLETION DATE 11-03-67 TENSILE TEST DATE MAR. 68

DATA TO BE USED FOR MATERIAL EVAL.
DO NOT USE FOR DESIGN

FIGURE 6-41 STRESS-STRAIN CURVES FOR WASPALOY. HIGH IRRAD
TESTED AT 1860 R (0.0013 IN./IN./MIN)

NPC 26,872



CURVE SYMBOL	SPECIMEN NUMBER	STRAIN MEAS. DEVICE	MINIMUM X-SECT. AREA (IN.^{2})	GAGE LENGTH (IN.)		FLUENCE (NEUTRONS/CM^2)		GAMMA DOSE (ERGS/ GM(C))
				NOMINAL	EFFECT.	THERMAL	FAST	
X	W39	INSTRON	0.0311		1.50	5.6+18	1.3+18	3.1+12
+	W40	INSTRON	0.0302		1.50	6.2+18	1.4+18	3.2+12
*	W43	INSTRON	0.0312		1.50	5.7+18	1.3+18	3.2+12

IRRAD. COMPLETION DATE 11-03-67 TENSILE TEST DATE MAR. 68

DATA TO BE USED FOR MATERIAL EVAL.
DO NOT USE FOR DESIGN

FIGURE 6-42 STRESS-STRAIN CURVES FOR WASPALOY. HIGH IRRAD
TESTED AT 1860 R (0.0013 IN./IN./MIN). FITTED TO HDBK MOD

Section 6.4

Presentation of
Inconel 718 Tensile Data

PRECEDING PAGE BLANK NOT FILMED.

INDEX TO INCONEL 718 TENSILE DATA

Material and Condition	Test Temp (^oR)	Spec. No.	Tensile Data Table	Tensile Data Page	Stat. Comparisons Abs. Value Table	Abs. Value Page	% Change Table	% Change Page	Effect of Boron Abs. Value Table	Abs. Value Page	% Change Table	% Change Page	Stress-Strain Curves Measured Fig.	Measured Page	Fitted Fig.	Fitted Page
0.6 ppm Boron																
Contr	1660	L 05 AGC[b]	6-7	6-78	6-8	6-82 6-83	6-9	6-84 6-85	6-10	6-86 6-87	6-11	6-88 6-89	6-43 -	6-90 -	6-44 -	6-91 -
Med Irrad	1660	L 01 L 02 L 12											6-45 ↓	6-92	6-46 ↓	6-93
High Irrad	1660	L 04 L 06 L 07											6-47 ↓	6-94	6-48 ↓	6-95
37 ppm Boron																
Contr	1360	N 02 N 03											6-49 ↓	6-96	6-50 ↓	6-97
	1510	N 08 N 10 N 11											6-51 ↓	6-98	6-52 ↓	6-99
Low Irrad	1510	N 12 N 13 N 14		6-79									6-53 ↓	6-100	6-54 ↓	6-101
Med Irrad	1510	N 15 N 17 N 19											6-55 ↓	6-102	6-56 ↓	6-103
High Irrad	1510	N 20 N 21 N 23											6-57 ↓	6-104	6-58 ↓	6-105
Contr	1585	N 04 N 58											6-59 ↓	6-106	6-60 ↓	6-107
Med Irrad	1585	N 05 N 06 N 07											6-61 ↓	6-108	6-62 ↓	6-109
Contr	1660	N 24 N 25 N 26		6-80									6-63 ↓	6-110	6-64 ↓	6-111
Low Irrad	1660	N 27 N 28 N 29											6-65 ↓	6-112	6-66 ↓	6-113
Med Irrad	1660	N 30 N 31 N 32											6-67 ↓	6-114	6-68 ↓	6-115
High Irrad	1660	N 33 N 34 N 35											6-69 ↓	6-116	6-70 ↓	6-117
Contr	1660	N 36[c] N 37[c] N 39[c]											6-71 ↓	6-118	6-72 ↓	6-119
Med Irrad	1660	N 41[c] N 42[c] N 43[c]		6-81									6-73 ↓	6-120	6-74 ↓	6-121
46 ppm Boron																
Contr	1660	AGC[d]											-	-	-	-
Med Irrad	1660	C 01 C 02 C 04											6-75 ↓	6-122	6-76 ↓	6-123
High Irrad	1660	C 05 C 08	↓		↓		↓		↓		↓		6-77 ↓	6-124	6-78 ↓	6-125

[a]Strain rate = 0.0013 in./in./min, except as noted. [b]L series; strain rate = 0.002 in./in./min

[c]Strain rate = 0.13 in./in./min [d]C series; strain rate = 0.002 in./in./min

Table 6-7

TENSILE TEST DATA FOR INDIVIDUAL SPECIMENS OF INCONEL 718
(L - 0.6 ppm B; N - 37 ppm B; C - 46 ppm B)

Specimen configuration: round-unnotched - Dwg. No. AGC 1134298-1,-3,-5. Data to be used for material evaluation only. Do not use for design.

Specimen Number	Condition	Strain Rate (in./in./min)	Test Temp (°R)	0.2% Offset Yield Stress (ksi)	Max Stress (ksi)	Frac Stress (ksi)	% Elongation		% Area Reduct (Bench)	Frac Location	Hardness Rockwell C		Radiation Exposure		
							Bench	Chart			Pre-Test	Post-Test	Gamma Dose [ergs/g(C)]	Neutron Fluence (n/cm^2) E > 1 MeV	Neutron Fluence (n/cm^2) E<0.48 eV
L 05	Control	0.0013	1660	142.41	146.47	136.41	4.08	3.51	6.35	(1) O		44.0			
L Series AGC data	Control	0.002	1660	136	152			10[a]	13						
				135	152			10[a]	14						
				136	147			8[a]	13.7						
Average				135.6	150.3			9.3	13.7						
Std Dev				5.8	2.9			1.2	0.6						
% Std Dev				0.4	1.9			12.9	4.2						
L 01	Irrad	0.0013	1660	141.12	148.46	146.87	2.30	1.95	15.58	(4) O			9.2(11)	8.80(16)	2.30(17)
L 02				145.88	152.76	146.52	3.17	2.84	10.72	(3) O	44.5	44.2	9.4(11)	9.00(16)	2.36(17)
L 12				146.69	152.76	147.01	3.55	2.94	11.74	(2) O			6.5(11)	4.20(16)	1.00(17)
Average				144.56	151.33	146.80	3.01	2.58	12.68						
Std Dev				3.01	2.48	0.25	0.64	0.55	2.56						
% Std Dev				2.08	1.64	0.17	21.3	21.1	20.2						
L 04	Irrad	0.0013	1660	142.04	142.36	142.36	0.12	0.17	15.39	(4) O			2.6(12)	8.20(17)	3.40(18)
L 06				151.00	151.64	146.52	0.47	0.57	18.59	(4) O	44.4	43.3	2.7(12)	8.70(17)	3.69(18)
L 07				143.82	143.82	143.82	0.27	0.22	16.43	(4) O			2.8(12)	9.30(17)	3.90(18)
Average				145.62	145.94	144.23	0.29	0.32	16.80						
Std Dev				4.74	4.99	2.11	0.18	0.22	1.63						
% Std Dev				3.26	3.42	1.46	61.2	68.1	9.71						
N 02	Control	0.0013	1360	147.87	167.58	153.59	16.05	16.36	41.15	(1) O	44.5	43.9			
N 03				147.50	166.34	144.31	17.95	17.43	43.96	(1) T	43.9	44.0			
N 08	Control	0.0013	1510	139.02	161.71	156.28	12.72	11.84	20.03	(1) T					
N 10				145.50	159.48	155.66	12.13	10.82	21.39	(2) O	43.0	41.5			
N 11				139.96	161.85	160.27	12.11	11.02	21.47	(2) O					
Average				141.49	161.01	157.40	12.32	11.23	20.96						
Std Dev				3.50	1.33	2.50	0.35	0.54	0.81						
% Std Dev				2.47	0.83	1.59	2.81	4.81	3.86						

[a]Elongation in 4 diameters

Table 6-7 (Cont'd)

Specimen Number	Condition	Strain Rate (in./in./min)	Test Temp (°R)	0.2% Offset Yield Stress (ksi)	Max Stress (ksi)	Frac Stress (ksi)	% Elongation Bench	% Elongation Chart	% Area Reduct (Bench)	Frac Location	Hardness, Rockwell C Pre-Test	Hardness, Rockwell C Post-Test	Radiation Exposure: Gamma Dose [ergs/g(C)]	Radiation Exposure: Neutron Fluence (n/cm²) E >1 MeV	Radiation Exposure: Neutron Fluence (n/cm²) E<0.48 eV
N 12	Irrad	0.0013	1510	147.16	165.40	159.64	10.46	9.81	20.39	(1) O			1.9(11)	3.40(15)	6.00(15)
N 13				142.57	159.79	156.28	9.13	7.36	15.19	(3) T	42.8	41.4	1.9(11)	3.30(15)	5.80(15)
N 14				136.60	161.06	156.62	10.45	9.11	18.26	(1) O			2.0(11)	4.25(15)	7.40(15)
Average				142.11	162.08	157.51	10.01	8.76	17.95						
Std Dev				5.30	2.94	1.85	0.77	1.26	2.61						
% Std Dev				3.73	1.81	1.17	7.64	14.4	14.6						
N 15	Irrad	0.0013	1510	141.08	159.00	151.96	8.51	7.19	17.60	(1) O			7.6(11)	5.50(16)	1.37(17)
N 17				145.47	165.84	162.97	9.03	8.58	20.35	(1) O	44.8	43.7	7.4(11)	5.20(16)	1.29(17)
N 19				149.27	168.08	165.22	5.18	7.48	17.93	(1) T			7.5(11)	6.60(16)	1.42(17)
Average				145.27	164.31	160.05	7.57	7.75	18.63						
Std Dev				4.10	4.73	7.10	2.09	0.73	1.50						
% Std Dev				2.82	2.88	4.43	27.6	9.46	8.06						
N 20	Irrad	0.0013	1510	145.98	165.03	159.31	7.49	6.90	13.31	(1) T			2.4(12)	6.58(17)	2.44(18)
N 21				144.16	161.71	156.28	7.78	6.33	17.9	(1) T	43.9	43.1	2.4(12)	6.50(17)	2.30(18)
N 23				149.95	169.32	168.05	5.14	7.42	19.16	(2) T			2.3(12)	6.40(17)	2.24(18)
Average				146.70	165.35	161.21	6.80	6.88	16.80						
Std Dev				2.96	3.82	6.11	1.45	0.55	3.08						
% Std Dev				2.02	2.31	3.79	21.3	7.92	18.4						
N 04	Control	0.0013	1585	146.42	159.15	156.93	8.18	7.01	17.19	(1) O					
N 58				136.29	150.90	148.99	6.38	5.16	14.14	(3) O					
Average				141.36	155.03	152.96	7.28	6.09	15.67						
Std Dev				7.16	5.83	5.61	1.27	1.31	2.16						
% Std Dev				5.07	3.76	3.67	17.5	21.5	13.8						
N 05	Irrad	0.0013	1585	140.26	153.71	151.15	5.31	4.82	15.31	(1) T	43.8	42.3	8.0(11)	6.10(16)	1.53(17)
N 06				140.69	153.42	151.51	4.62	3.70	13.51	(2) T			7.8(11)	6.00(16)	1.50(17)
N 07				136.96	152.82	151.86	5.13	4.02	10.11	(2) T			7.7(11)	5.80(16)	1.41(17)
Average				139.30	153.32	151.51	5.02	4.18	12.98						
Std Dev				2.04	0.45	0.36	0.36	0.58	2.64						
% Std Dev				1.46	0.30	0.23	7.13	13.8	20.3						

Table 6-7 (Cont'd)

Specimen Number	Condition	Strain Rate (in./in. /min)	Test Temp (^oR)	0.2% Offset Yield Stress (ksi)	Max Stress (ksi)	Frac Stress (ksi)	% Elongation: Bench	% Elongation: Chart	% Area Reduct (Bench)	Frac Loca-tion	Hardness, Rockwell C: Pre-Test	Hardness, Rockwell C: Post-Test	Radiation Exposure: Gamma Dose [ergs/g(C)]	Radiation Exposure: Neutron Fluence (n/cm^2): E >1 MeV	Radiation Exposure: Neutron Fluence (n/cm^2): E<0.48 eV
N 24	Control	0.0013	1660	142.78	149.46	145.96	5.93	5.41	15.91	(2) T					
N 25				137.60	145.84	142.67	4.74	3.67	13.85	(3) T					
N 26				144.26	152.18	147.11	5.55	4.68	12.46	(1) T	44.7	44.0			
Average				141.55	149.16	145.25	5.41	4.59	14.07						
Std Dev				3.50	3.18	2.30	0.61	0.87	1.74						
% Std Dev				2.47	2.13	1.59	11.2	19.0	12.3						
N 27	Irrad	0.0013	1660	142.78	149.46	146.28	4.93	3.36	9.36	(1) T	44.1	43.2	2.0(11)	4.40(15)	7.70(15)
N 28				142.89	149.27	147.35	3.82	2.68	14.27	(2) T			2.1(11)	4.50(15)	8.00(15)
N 29				138.65	146.28	144.37	4.05	3.00	9.10	(1) O			2.2(11)	4.70(15)	8.30(15)
Average				141.44	148.34	146.00	4.27	3.01	10.91						
Std Dev				2.42	1.78	1.51	0.59	0.34	2.91						
% Std Dev				1.71	1.20	1.03	13.7	11.3	26.7						
N 30	Irrad	0.0013	1660	137.10	142.86	140.62	3.38	1.85	10.34	(1) T			7.8(11)	7.00(16)	1.69(17)
N 31				137.56	144.92	142.68	3.17	2.11	11.67	(1) T	44.1	42.3	8.1(11)	7.40(16)	1.82(17)
N 32				137.56	143.96	139.16	3.70	2.02	5.92	(2) O			8.4(11)	7.80(16)	1.94(17)
Average				137.41	143.91	140.82	3.42	1.99	9.31						
Std Dev				0.27	1.03	1.77	0.27	0.13	3.01						
% Std Dev				0.19	0.72	1.26	7.81	6.62	32.3						
N 33	Irrad	0.0013	1660	137.01	144.02	140.84	2.97	1.52	7.27	(1) T			2.3(12)	6.20(17)	2.19(18)
N 34				137.15	144.80	143.53	2.61	1.20	12.87	(2) T	43.4	43.3	2.3(12)	5.95(17)	2.05(18)
N 35				136.29	142.96	141.37	3.90	1.12	6.58	(1) T			2.5(12)	7.60(17)	3.18(18)
Average				136.82	143.93	141.91	3.16	1.28	8.91						
Std Dev				0.46	0.92	1.42	0.67	0.21	3.45						
% Std Dev				0.34	0.64	1.00	21.1	16.5	38.7						
N 36	Control	0.13	1660	133.24	152.96	146.28	12.92	13.00	25.68	(1) O	43.8	43.2			
N 37				134.06	152.49	146.45	12.45	11.69	27 89	(2) O					
N 39				143.38	162.50	147.85	12.78	13.00	28.53	(1) O					
Average				136.89	155.98	146.86	12.72	12.56	27.37						
Std Dev				5.63	5.65	0.86	0.24	0.76	1.50						
% Std Dev				4.11	3.62	0.59	1.90	6.02	5.46						

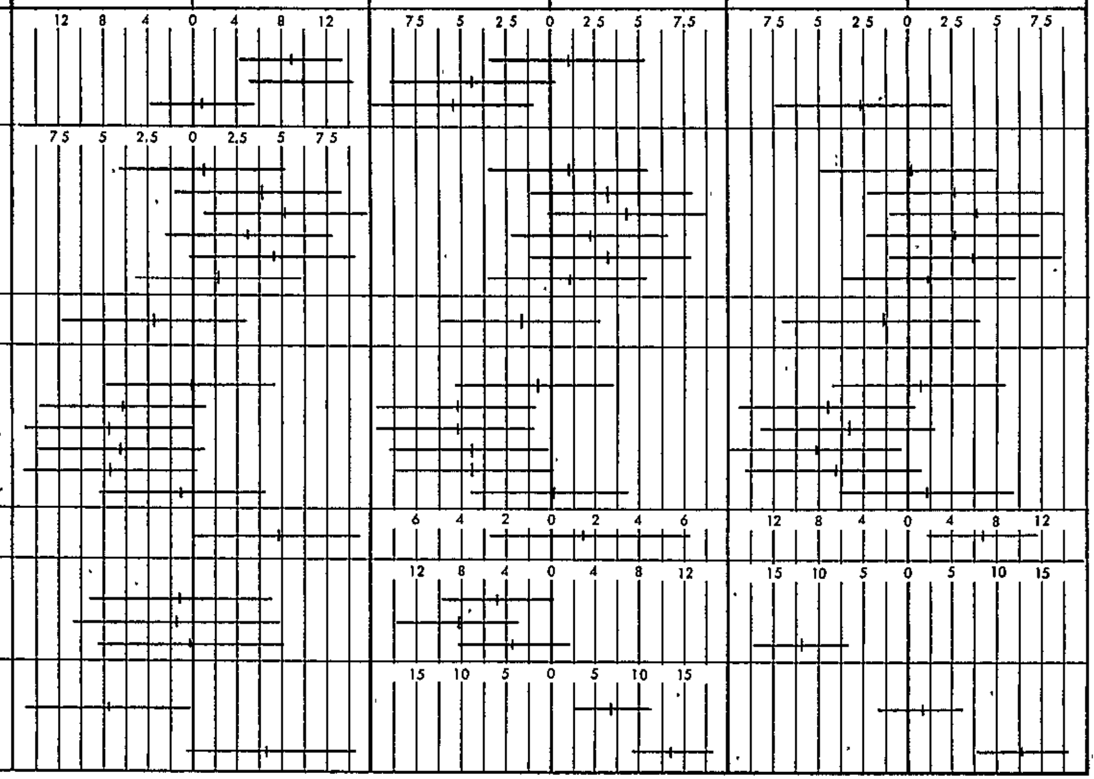
Table 6-7 (Cont'd)

Specimen Number	Condition	Strain Rate (in./in./min)	Test Temp (°R)	0.2% Offset Yield Stress (ksi)	Max Stress (ksi)	Frac Stress (ksi)	% Elongation		% Area Reduct (Bench)	Frac Location	Hardness, Rockwell C		Radiation Exposure		
							Bench	Chart			Pre-Test	Post-Test	Gamma Dose [ergs/g(C)]	Neutron Fluence (n/cm^2) E >1 MeV	Neutron Fluence (n/cm^2) E<0.48 eV
N 41	Irrad	0.13	1660	143.39	159.32	156.13	9.20	8.21	21.16	(1) T			8.6(11)	8.00(16)	2.06(17)
N 42				141.01	158.20	152.79	10.00	8.43	24.48	(1) T	44.4	43.6	8.8(11)	8.40(16)	2.18(17)
N 43				140.69	155.65	151.83	9.13	7.92	23.62	(1) T			9.0(11)	8.60(16)	2.25(17)
Average				141.70	157.72	153.58	9.44	8.19	23.09						
Std Dev				1.48	1.88	2.26	0.48	0.26	1.72						
% Std Dev				1.04	1.19	1.47	5.12	3.12	7.46						
C Series AGC data	Control	0.002	1660	133.0	148.0			10.0[a]	12.2						
				129.0	142.0			8.0[a]	8.8						
Average				131.00	145.0			9.0	10.5						
Std Dev				2.83	4.2			1.4	2.4						
% Std Dev				2.16	2.9			15.7	22.9						
C 01	Irrad	0.0013	1660	130.55	142.25	109.06	7.53	6.68	15.05	(3) T	40.2	42.6	9.4(11)	8.95(16)	2.36(17)
C 02				129.79	138.63	113.68	5.19	4.47	10.45	(1) T			9.3(11)	8.80(16)	2.30(17)
C 04				130.51	139.42	116.82	4.45	4.35	12.61	(3) T			9.2(11)	8.40(16)	2.20(17)
Average				130.28	140.10	113.1	5.72	5.17	12.70						
Std Dev				0.43	1.90	3.90	1.61	1.31	2.30						
% Std Dev				0.33	1.36	3.45	28.1	25.4	18.1						
C 05	Irrad	0.0013	1660	130.25	136.60	95.30	4.71	3.81	16.90	(1) T	42.7	42.2	2.8(12)	9.70(17)	4.10(18)
C 08				129.99	136.96	107.16	6.23	3.55	14.33	(1) T			2.9(12)	1.00(18)	4.30(18)
Average				130.12	136.78	101.23	5.47	3.68	15.62						
Std Dev				0.18	0.25	8.39	1.07	0.18	1.82						
% Std Dev				0.14	0.19	8.28	19.6	5.00	11.6						

Table 6-8

EFFECT OF TEST CONDITIONS ON THE TENSILE PROPERTIES OF INCONEL 718 - COMPARISON ON AN ABSOLUTE-VALUE BASIS

Material Code[a]	Test Temp (°R)	Strain Rate (in./in./min)	Specimen Data Compared[b]	90% Confidence Interval on Difference Between Averages Compared: 0.2% Offset Yield Stress (ksi) (-) 0 (+)	Maximum Stress (ksi) (-) 0 (+)	Fracture Stress (ksi) (-) 0 (+)
L	1660	0.0013	Control vs med irrad Control vs high irrad Med irrad vs high irrad			
N	1510	0.0013	Control vs low irrad Control vs med irrad Control vs high irrad Low irrad vs med irrad Low irrad vs high irrad Med irrad vs high irrad			
N	1585	0.0013	Control vs med irrad			
N	1660	0.0013	Control vs low irrad Control vs med irrad Control vs high irrad Low irrad vs med irrad Low irrad vs high irrad Med irrad vs high irrad			
N	1660	0.13	Control vs med irrad			
C	1660	0.0013	Control vs med irrad Control vs high irrad Med irrad vs high irrad			
N	1660	As compared	Control 0.0013 vs 0.13 in./in./min Medium irradiation 0.0013 vs 0.13 in./in./min			

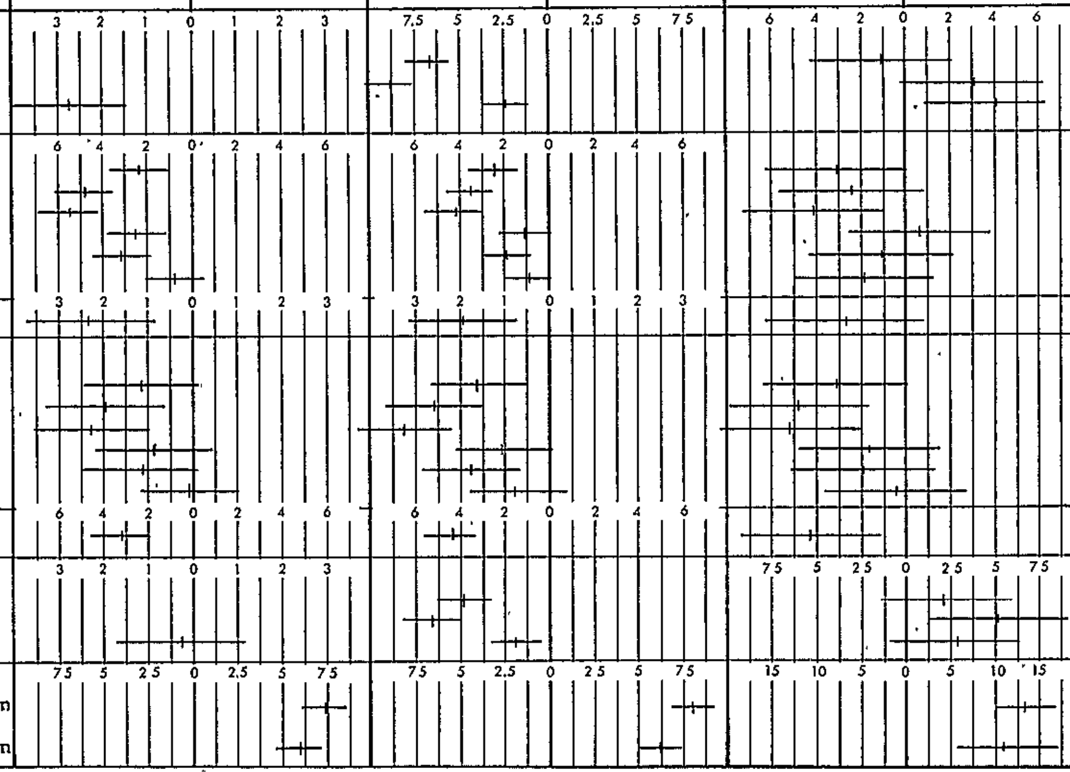


[a]L, 0.6 ppm boron; N, 37 ppm boron; C, 46 ppm boron

[b]Comparison is always second condition compared to the first condition.

Table 6-8 (Cont'd)

Material Code[a]	Test Temp (°R)	Strain Rate (in./in./min)	Specimen Data Compared[b]	90% Confidence Interval on Difference Between Averages Compared: % Elongation - Bench (-) 0 (+)	% Elongation - Chart (-) 0 (+)	% Area Reduction (-) 0 (+)
L	1660	0.0013	Control vs med irrad Control vs high irrad Med irrad vs high irrad			
N	1510	0.0013	Control vs low irrad Control vs med irrad Control vs high irrad Low irrad vs med irrad Low irrad vs high irrad Med irrad vs high irrad			
N	1585	0.0013	Control vs med irrad			
N	1660	0.0013	Control vs low irrad Control vs med irrad Control vs high irrad Low irrad vs med irrad Low irrad vs high irrad Med irrad vs high irrad			
N	1660	0.13	Control vs med irrad			
C	1660	0.0013	Control vs med irrad Control vs high irrad Med irrad vs high irrad			
N	1660	As compared	Control 0.0013 vs 0.13 in./in./min Medium irradiation 0.0013 vs 0.13 in./in./min			



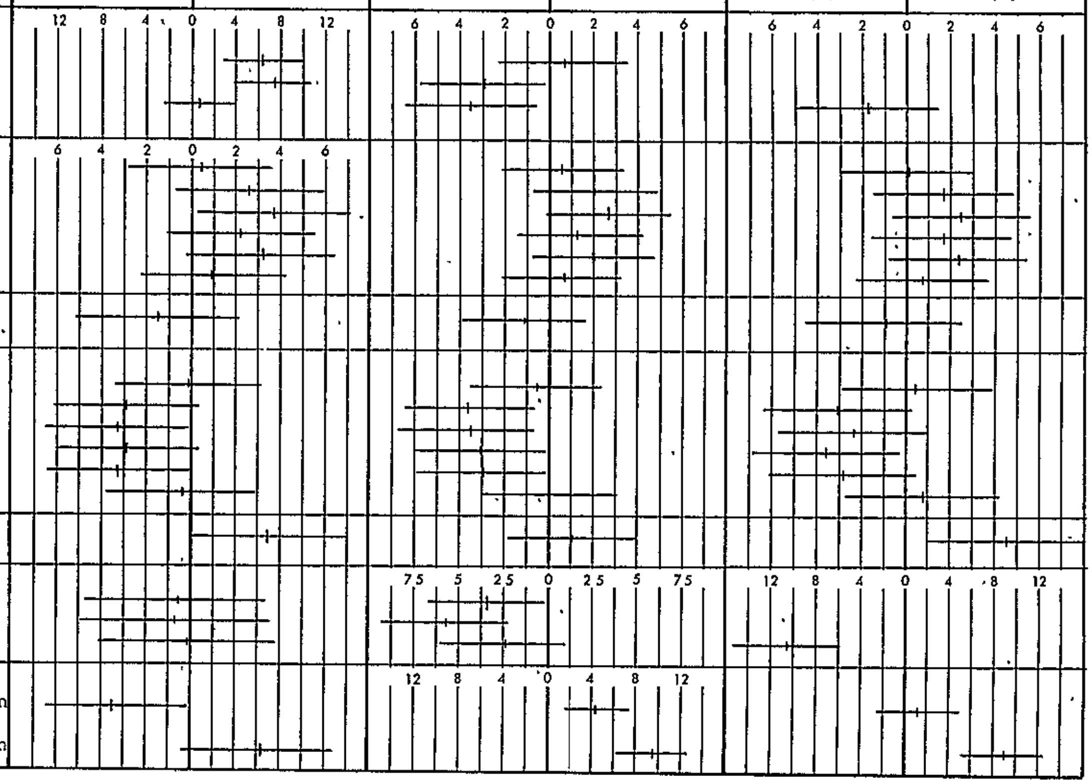
[a]L, 0.6 ppm boron; N, 37 ppm boron; C, 46 ppm boron

[b]Comparison is always second condition compared to the first condition.

Table 6-9

EFFECT OF TEST CONDITIONS ON THE TENSILE PROPERTIES OF INCONEL 718 - COMPARISON ON A PERCENT-CHANGE BASIS

Material Code[a]	Test Temp (°R)	Strain Rate (in./in./min)	Specimen Data Compared[b]	90% Confidence Interval on Difference Between Averages Compared: 0.2% Offset Yield Stress (-) 0 (+)	Maximum Stress (-) 0 (+)	Fracture Stress (-) 0 (+)
L	1660	0.0013	Control vs med irrad Control vs high irrad Med irrad vs high irrad	12 8 4 0 4 8 12	6 4 2 0 2 4 6	6 4 2 0 2 4 6
N	1510	0.0013	Control vs low irrad Control vs med irrad Control vs high irrad Low irrad vs med irrad Low irrad vs high irrad Med irrad vs high irrad	6 4 2 0 2 4 6		
N	1585	0.0013	Control vs med irrad			
N	1660	0.0013	Control vs low irrad Control vs med irrad Control vs high irrad Low irrad vs med irrad Low irrad vs high irrad Med irrad vs high irrad			
N	1660	0.13	Control vs med irrad			
C	1660	0.0013	Control vs med irrad Control vs high irrad Med irrad vs high irrad		7.5 5 2.5 0 2.5 5 7.5	12 8 4 0 4 8 12
N	1660	As compared	Control 0.0013 vs 0.13 in./in./min Medium irradiation 0.0013 vs 0.13 in./in./min		12 8 4 0 4 8 12	

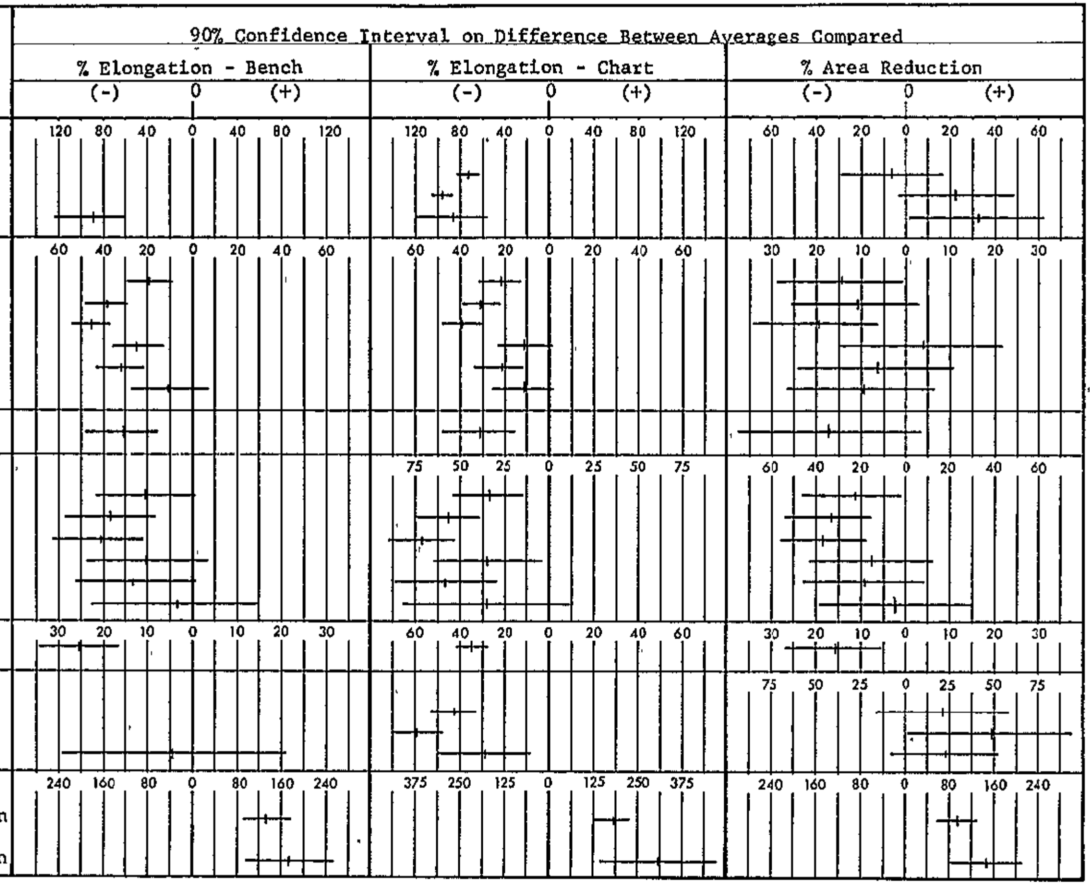


[a]L, 0.6 ppm boron; N, 37 ppm boron; C, 46 ppm boron

[b]Comparison is always second condition compared to the first condition.

Table 6-9 (Cont'd)

Material Code[a]	Test Temp (°R)	Strain Rate (in./in./min)	Specimen Data Compared[b]
L	1660	0.0013	Control vs med irrad Control vs high irrad Med irrad vs high irrad
N	1510	0.0013	Control vs low irrad Control vs med irrad Control vs high irrad Low irrad vs med irrad Low irrad vs high irrad Med irrad vs high irrad
N	1585	0.0013	Control vs med irrad
N	1660	0.0013	Control vs low irrad Control vs med irrad Control vs high irrad Low irrad vs med irrad Low irrad vs high irrad Med irrad vs high irrad
N	1660	0.13	Control vs med irrad
C	1660	0.0013	Control vs med irrad Control vs high irrad Med irrad vs high irrad
N	1660	As compared	Control 0.0013 vs 0.13 in./in./min Medium irradiation 0.0013 vs 0.13 in./in./min



[a]L, 0.6 ppm boron; N, 37 ppm boron; C, 46 ppm boron

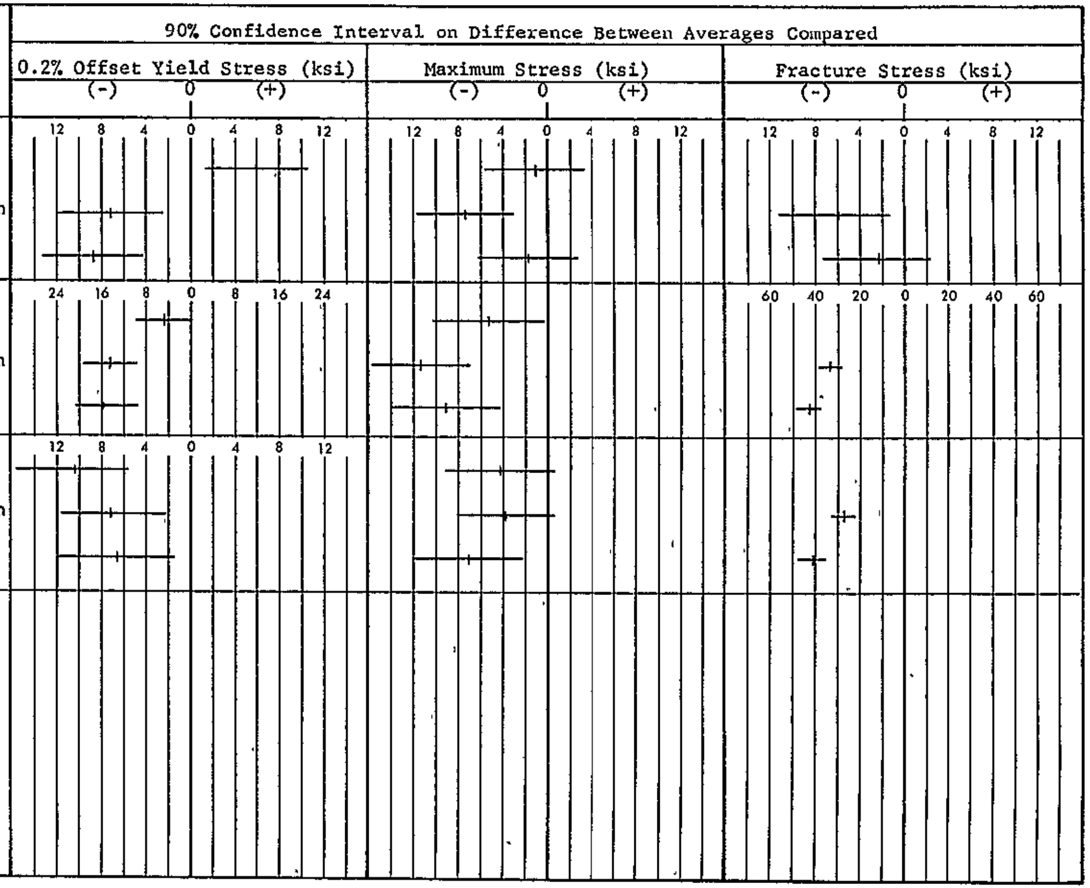
[b]Comparison is always second condition compared to the first condition.

Table 6-10

EFFECT OF BORON CONTENT ON THE TENSILE PROPERTIES OF INCONEL 718 - COMPARISON ON AN ABSOLUTE-VALUE BASIS

Material Code[a]	Test Temp (°R)	Strain Rate (in./in./min)	Specimen Data Compared[b]
L-N	1660	0.0013	L vs N, control L vs N, medium irradiation L vs N, high irradiation
L-C	1660	0.0013	L vs C, control L vs C, medium irradiation L vs C, high irradiation
N-C	1660	0.0013	N vs C, control N vs C, medium irradiation N vs C, high irradiation

90% Confidence Interval on Difference Between Averages Compared

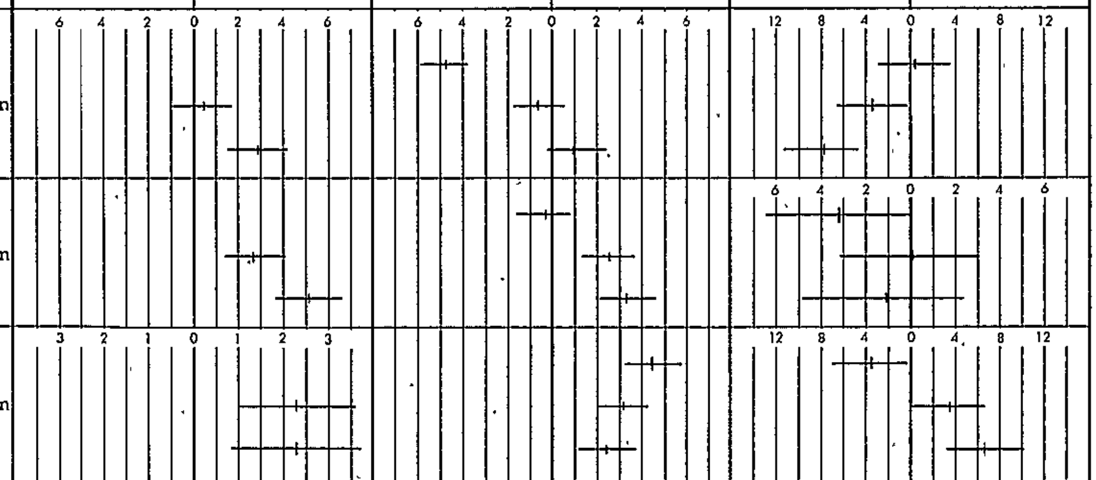


[a]L, 0.6 ppm boron; N, 37 ppm boron; C, 46 ppm boron

[b]Comparison is always second condition compared to the first condition.

Table 6-10 (Cont'd)

Material Code[a]	Test Temp (°R)	Strain Rate (in./in./min)	Specimen Data Compared[b]	90% Confidence Interval on Difference Between Averages Compared		
				% Elongation - Bench (-) 0 (+)	% Elongation - Chart (-) 0 (+)	% Area Reduction (-) 0 (+)
L-N	1660	0.0013	L vs N, control			
			L vs N, medium irradiation			
			L vs N, high irradiation			
L-C	1660	0.0013	L vs C, control			
			L vs C, medium irradiation			
			L vs C, high irradiation			
N-C	1660	0.0013	N vs C, control			
			N vs C, medium irradiation			
			N vs C, high irradiation			



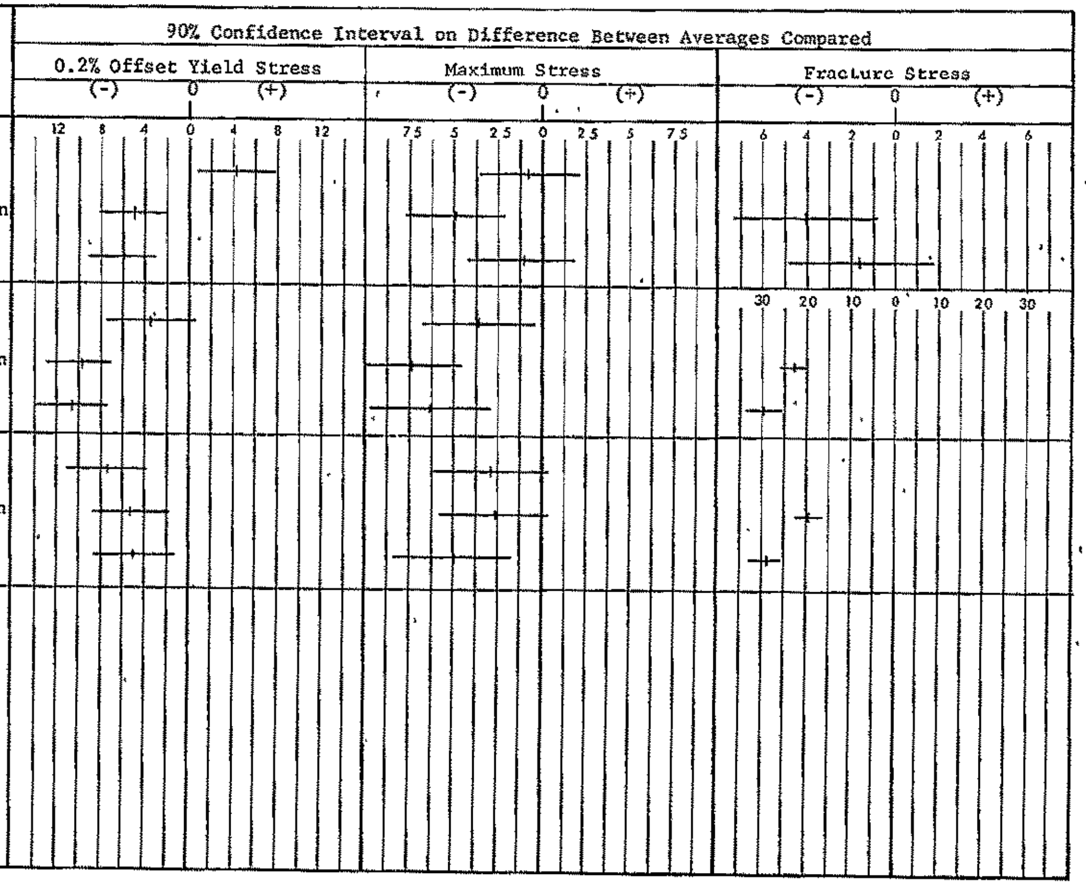
[a]L, 0.6 ppm boron; N, 37 ppm boron; C, 46 ppm boron

[b]Comparison is always second condition compared to the first condition.

Table 6-11

EFFECT OF BORON CONTENT ON THE TENSILE PROPERTIES OF INCONEL 718 - COMPARISON ON A PERCENT-CHANGE BASIS

Material Code[a]	Test Temp (°R)	Strain Rate (in./in./min)	Specimen Data Compared[b]
L-N	1660	0.0013	L vs N, control
			L vs N, medium irradiation
			L vs N, high irradiation
L-C	1660	0.0013	L vs C, control
			L vs C, medium irradiation
			L vs C, high irradiation
N-C	1660	0.0013	N vs C, control
			N vs C, medium irradiation
			N vs C, high irradiation

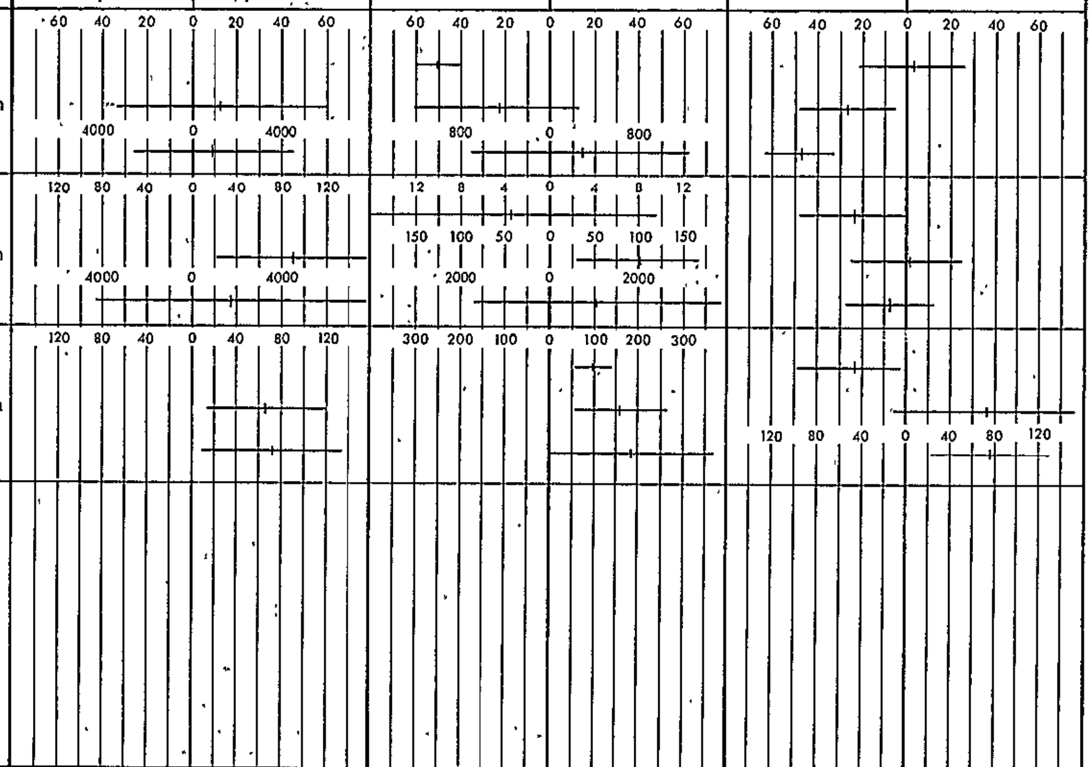


[a]L, 0.6 ppm boron; N, 37 ppm boron; C, 46 ppm boron

[b]Comparison is always second condition compared to the first condition.

Table 6-11 (Cont'd)

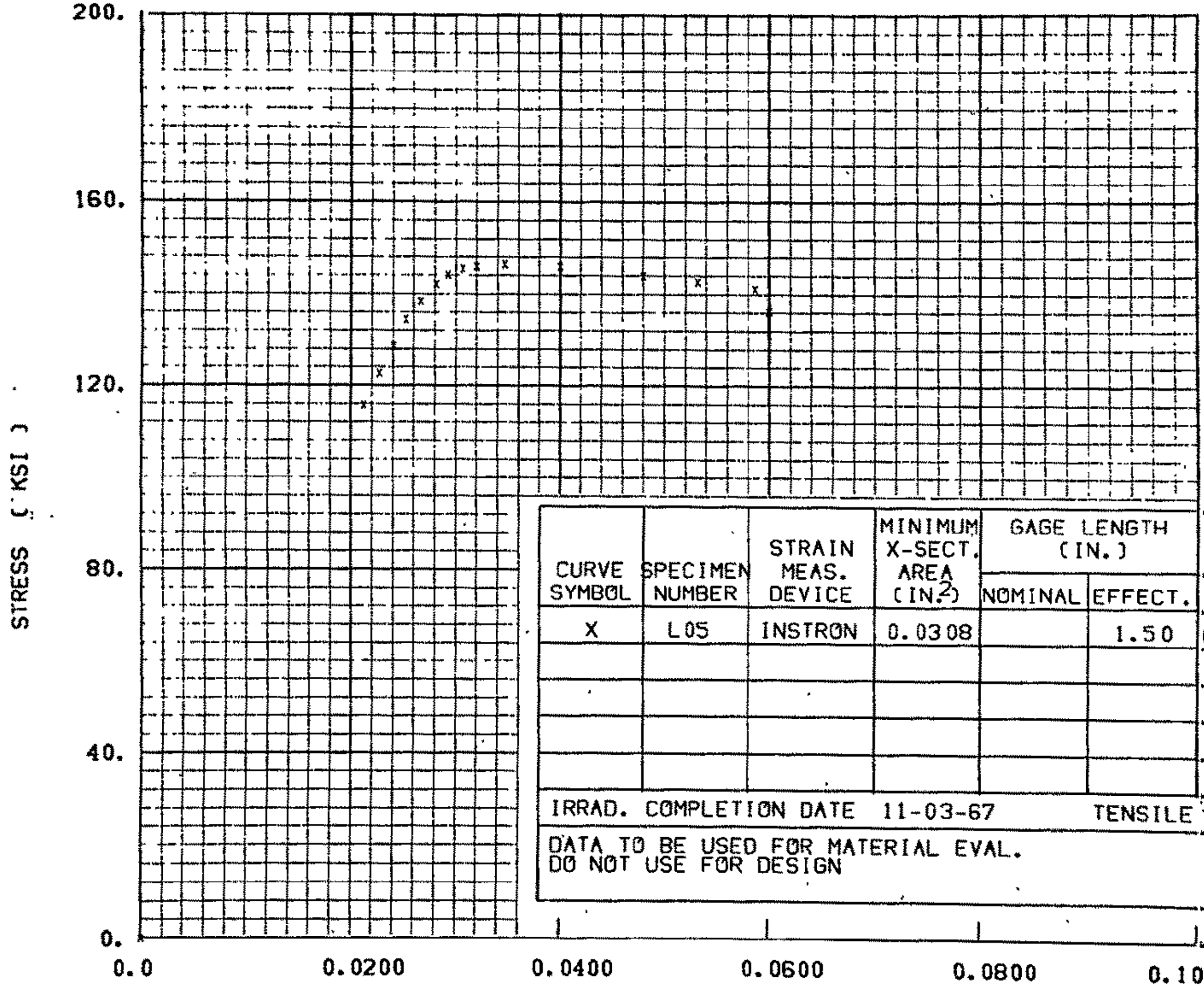
Material Code[a]	Test Temp (°R)	Strain Rate (in./in./min)	Specimen Data Compared[b]	90% Confidence Interval on Difference Between Averages Compared: % Elongation - Bench (-) 0 (+)	% Elongation - Chart (-) 0 (+)	% Area Reduction (-) 0 (+)
L-N	1660	0.0013	L vs N, control			
			L vs N, medium irradiation			
			L vs N, high irradiation			
L-C	1660	0.0013	L vs C, control			
			L vs C, medium irradiation			
			L vs C, high irradiation			
N-C	1660	0.0013	N vs C, control			
			N vs C, medium irradiation			
			N vs C, high irradiation			



[a]L, 0.6 ppm boron; N, 37 ppm boron; C, 46 ppm boron

[b]Comparison is always second condition compared to the first condition.

6-90



CURVE SYMBOL	SPECIMEN NUMBER	STRAIN MEAS. DEVICE	MINIMUM X-SECT. AREA ($IN.^2$)	GAGE LENGTH (IN.) NOMINAL	GAGE LENGTH (IN.) EFFECT.	FLUENCE ($NEUTRONS/CM^2$) THERMAL	FLUENCE ($NEUTRONS/CM^2$) FAST	GAMMA DOSE (ERGS/GM(C))
X	L05	INSTRON	0.0308		1.50	CONT		

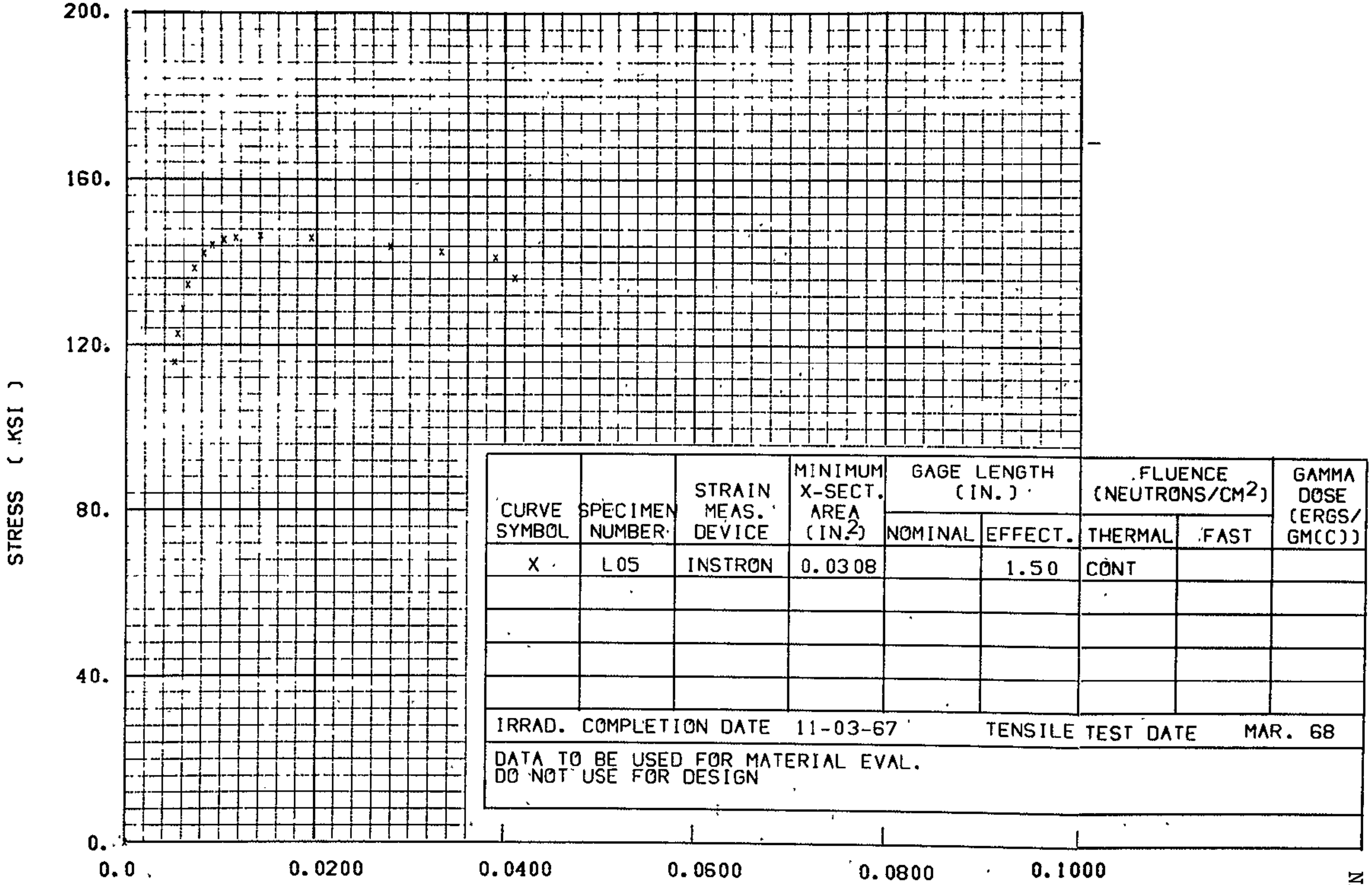
IRRAD. COMPLETION DATE 11-03-67 TENSILE TEST DATE MAR. 68

DATA TO BE USED FOR MATERIAL EVAL.
DO NOT USE FOR DESIGN

STRAIN (IN./IN. OF GAGE LENGTH)(BASED ON CROSSHEAD TRAVEL)

FIGURE 6-43 STRESS-STRAIN CURVES FOR INCONEL 718(.6 PPM B).
CONTROLS. TESTED AT 1660 R (0.0013 IN./IN./MIN)

NPC 26,874



CURVE SYMBOL	SPECIMEN NUMBER	STRAIN MEAS. DEVICE	MINIMUM X-SECT. AREA (IN.^{2})	GAGE LENGTH (IN.) NOMINAL	GAGE LENGTH (IN.) EFFECT.	FLUENCE (NEUTRONS/CM^2) THERMAL	FLUENCE (NEUTRONS/CM^2) FAST	GAMMA DOSE (ERGS/GM(C))
X	L05	INSTRON	0.0308		1.50	CONT		

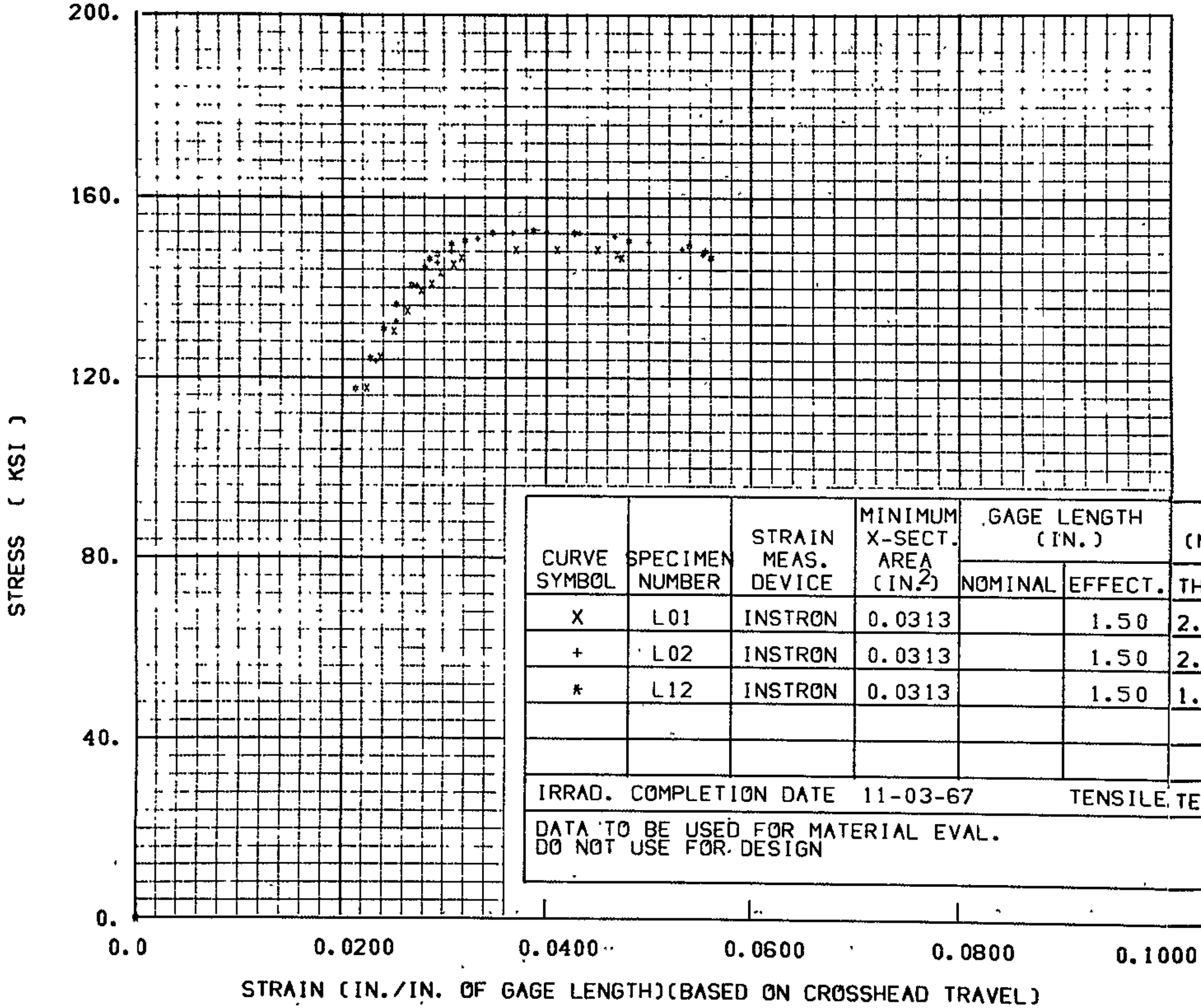
IRRAD. COMPLETION DATE 11-03-67 TENSILE TEST DATE MAR. 68

DATA TO BE USED FOR MATERIAL EVAL.
DO NOT USE FOR DESIGN

STRAIN (IN./IN. OF GAGE LENGTH)(BASED ON HANDBOOK MODULUS)

FIGURE 6-44 STRESS-STRAIN CURVES FOR INCONEL 718(.6 PPM B). CONTROLS. 1660 R (0.0013 IN./IN./MIN). FITTED TO HDBK MOD

NPC 26,875



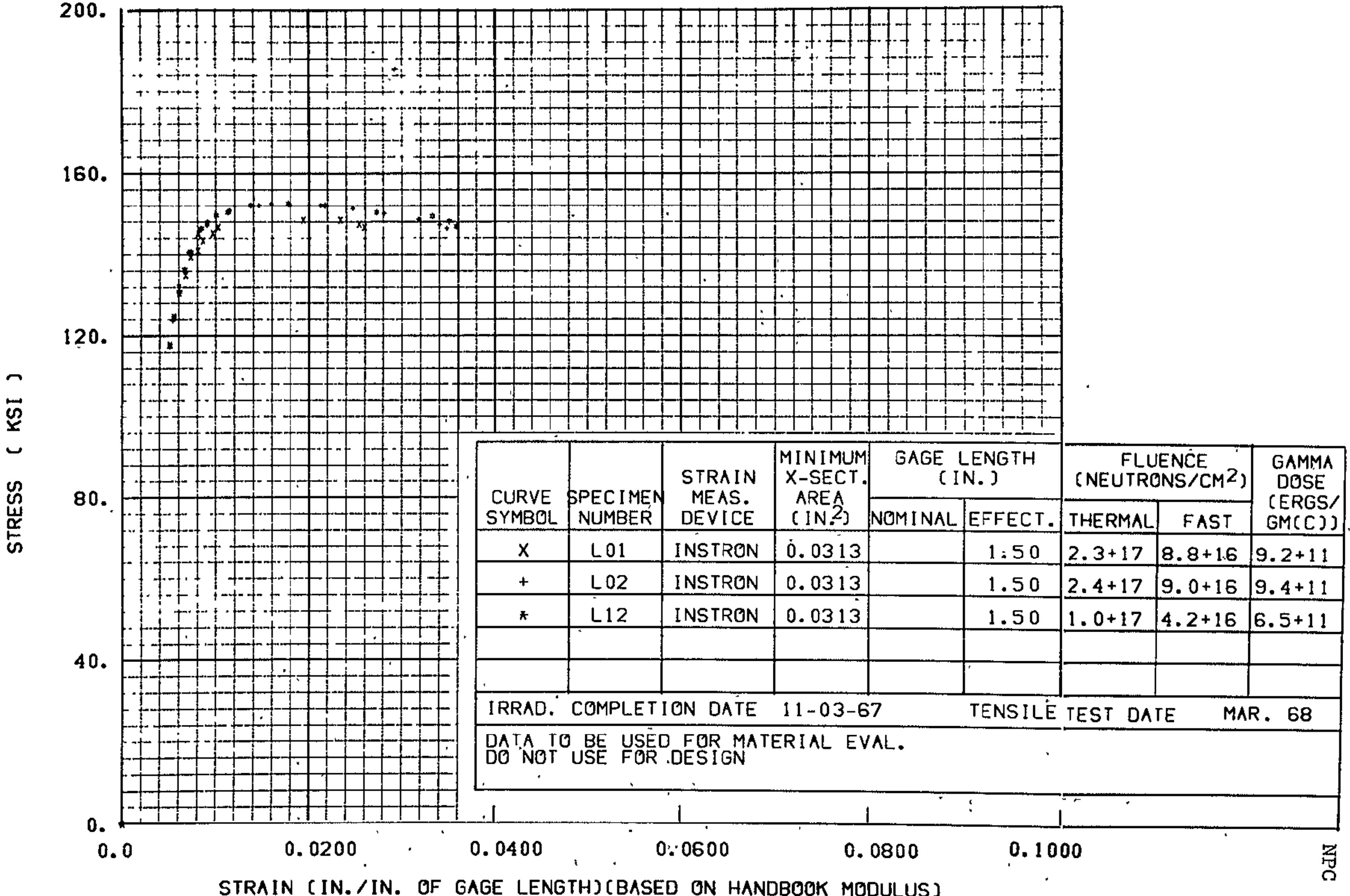
CURVE SYMBOL	SPECIMEN NUMBER	STRAIN MEAS. DEVICE	MINIMUM X-SECT. AREA (IN.^{2})	GAGE LENGTH (IN.) NOMINAL	GAGE LENGTH (IN.) EFFECT.	FLUENCE (NEUTRONS/CM^2) THERMAL	FLUENCE (NEUTRONS/CM^2) FAST	GAMMA DOSE (ERGS/ GM(C))
X	L01	INSTRON	0.0313		1.50	2.3+17	8.8+16	9.2+11
+	L02	INSTRON	0.0313		1.50	2.4+17	9.0+16	9.4+11
*	L12	INSTRON	0.0313		1.50	1.0+17	4.2+16	6.5+11

IRRAD. COMPLETION DATE 11-03-67 TENSILE TEST DATE MAR. 68

DATA TO BE USED FOR MATERIAL EVAL.
DO NOT USE FOR DESIGN

FIGURE 6-45 STRESS-STRAIN CURVES FOR INCONEL 718(.6 PPM B). MED IRRAD. TESTED AT 1660 R (0.0013 IN./IN./MIN)

NPC 26,876



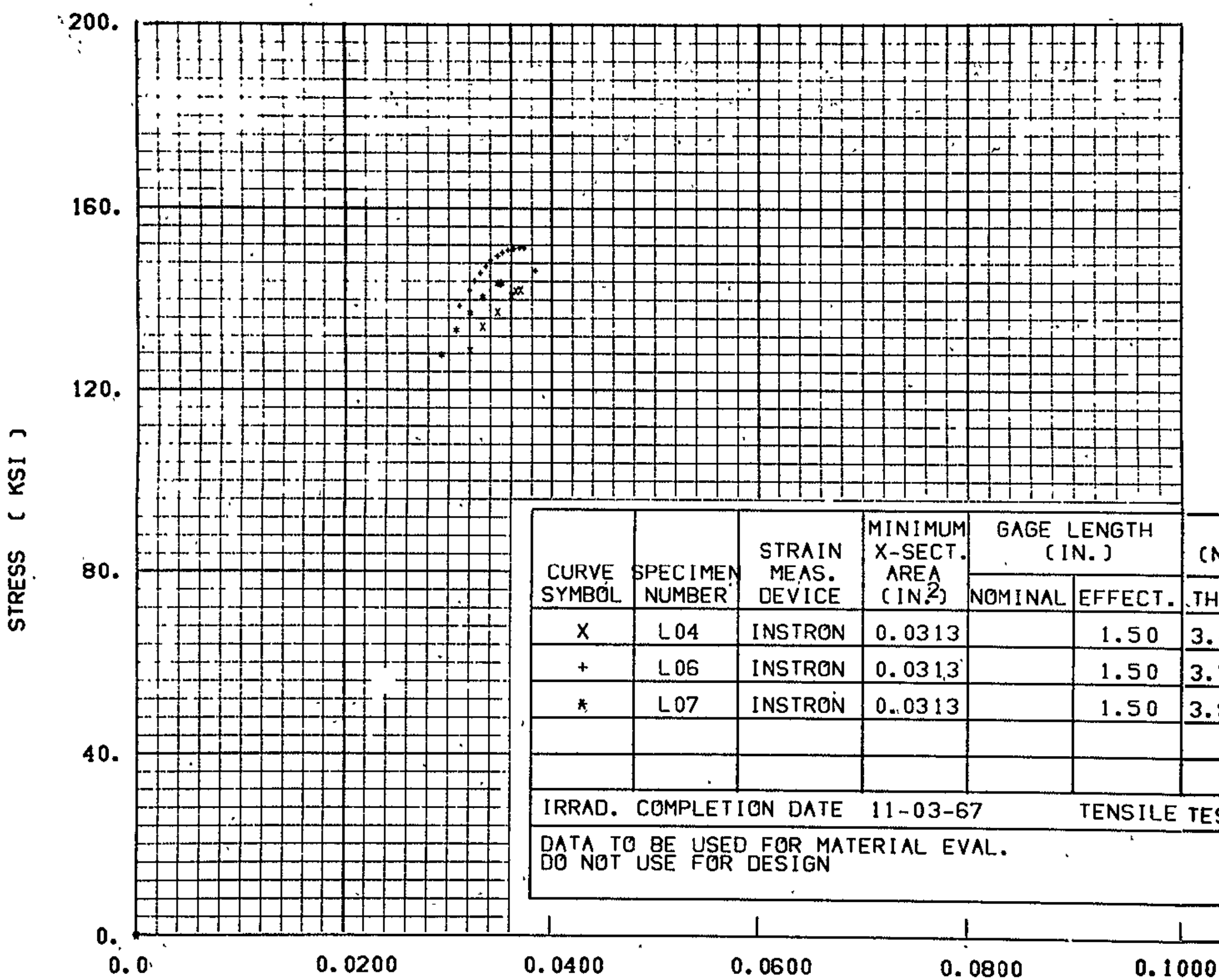
CURVE SYMBOL	SPECIMEN NUMBER	STRAIN MEAS. DEVICE	MINIMUM X-SECT. AREA ($IN.^2$)	GAGE LENGTH (IN.) NOMINAL	GAGE LENGTH (IN.) EFFECT.	FLUENCE (NEUTRONS/CM^2) THERMAL	FLUENCE (NEUTRONS/CM^2) FAST	GAMMA DOSE (ERGS/GM(C))
X	L01	INSTRON	0.0313		1.50	2.3+17	8.8+16	9.2+11
+	L02	INSTRON	0.0313		1.50	2.4+17	9.0+16	9.4+11
*	L12	INSTRON	0.0313		1.50	1.0+17	4.2+16	6.5+11

IRRAD. COMPLETION DATE 11-03-67 TENSILE TEST DATE MAR. 68

DATA TO BE USED FOR MATERIAL EVAL.
DO NOT USE FOR DESIGN

FIGURE 6-46 STRESS-STRAIN CURVES FOR INCONEL 718(.6 PPM B).
MED IRRAD. 1660 R (0.0013 IN./IN./MIN). FITTED TO HDBK MOD

NPC 26,877

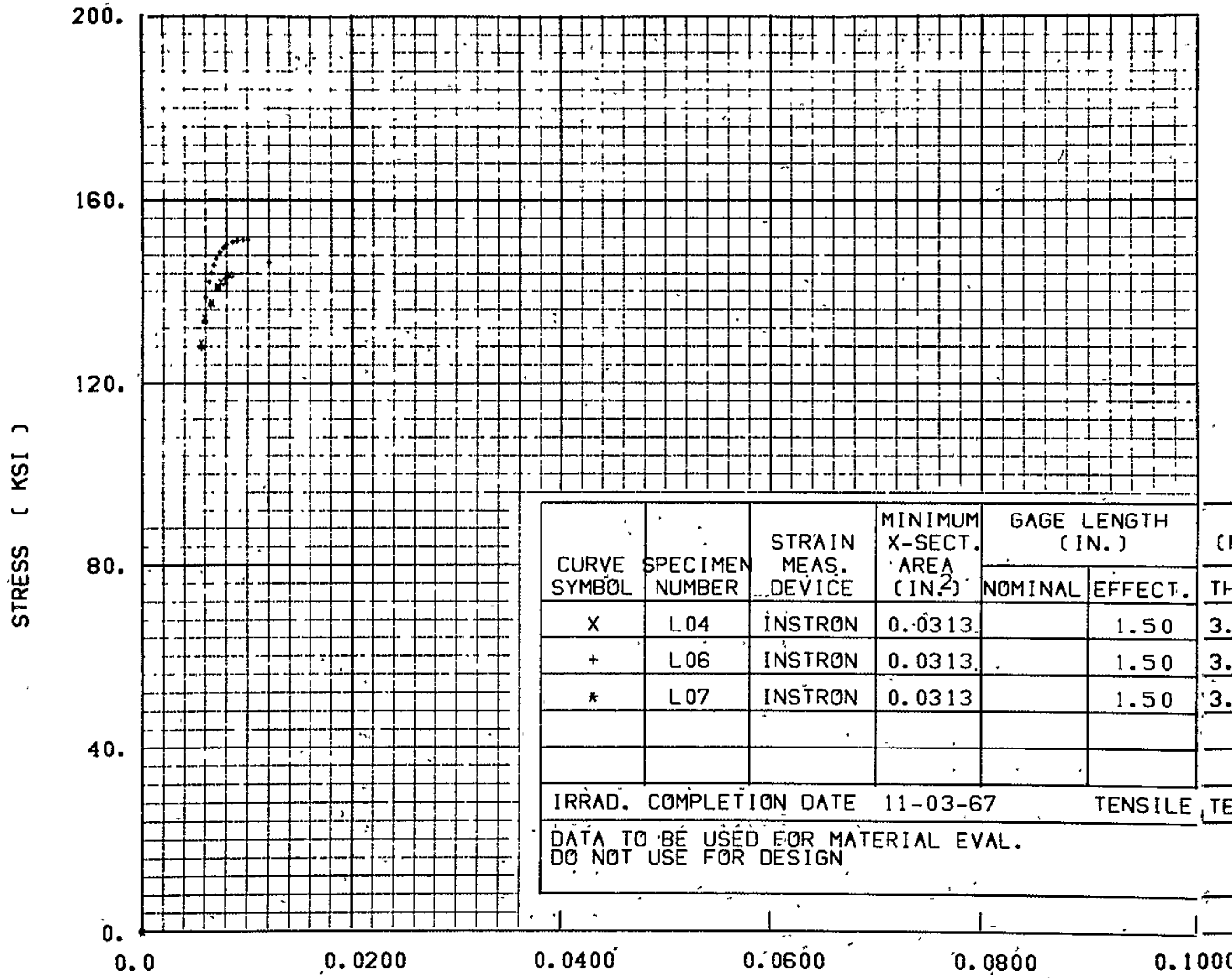


CURVE SYMBOL	SPECIMEN NUMBER	STRAIN MEAS. DEVICE	MINIMUM X-SECT. AREA (IN.^{2})	GAGE LENGTH (IN.) NOMINAL	GAGE LENGTH (IN.) EFFECT.	FLUENCE (NEUTRONS/CM^2) THERMAL	FLUENCE (NEUTRONS/CM^2) FAST	GAMMA DOSE (ERGS/GM(C))
X	L04	INSTRON	0.0313		1.50	3.4+18	8.2+17	2.6+11
+	L06	INSTRON	0.0313		1.50	3.7+18	8.7+17	2.7+11
*	L07	INSTRON	0.0313		1.50	3.9+18	9.3+17	2.8+11

IRRAD. COMPLETION DATE 11-03-67 TENSILE TEST DATE MAR. 68

DATA TO BE USED FOR MATERIAL EVAL.
DO NOT USE FOR DESIGN

FIGURE 6-47 STRESS-STRAIN CURVES FOR INCONEL 718(.6 PPM B).
HIGH IRRAD. TESTED AT 1660 R (0.0013 IN./IN./MIN)



CURVE SYMBOL	SPECIMEN NUMBER	STRAIN MEAS. DEVICE	MINIMUM X-SECT. AREA (IN.^{2})	GAGE LENGTH (IN.) NOMINAL	GAGE LENGTH (IN.) EFFECT.	FLUENCE (NEUTRONS/CM^2) THERMAL	FLUENCE (NEUTRONS/CM^2) FAST	GAMMA DOSE (ERGS/GM(C))
X	L04	INSTRON	0.0313		1.50	3.4+18	8.2+17	2.6+11
+	L06	INSTRON	0.0313		1.50	3.7+18	8.7+17	2.7+11
*	L07	INSTRON	0.0313		1.50	3.9+18	9.3+17	2.8+11

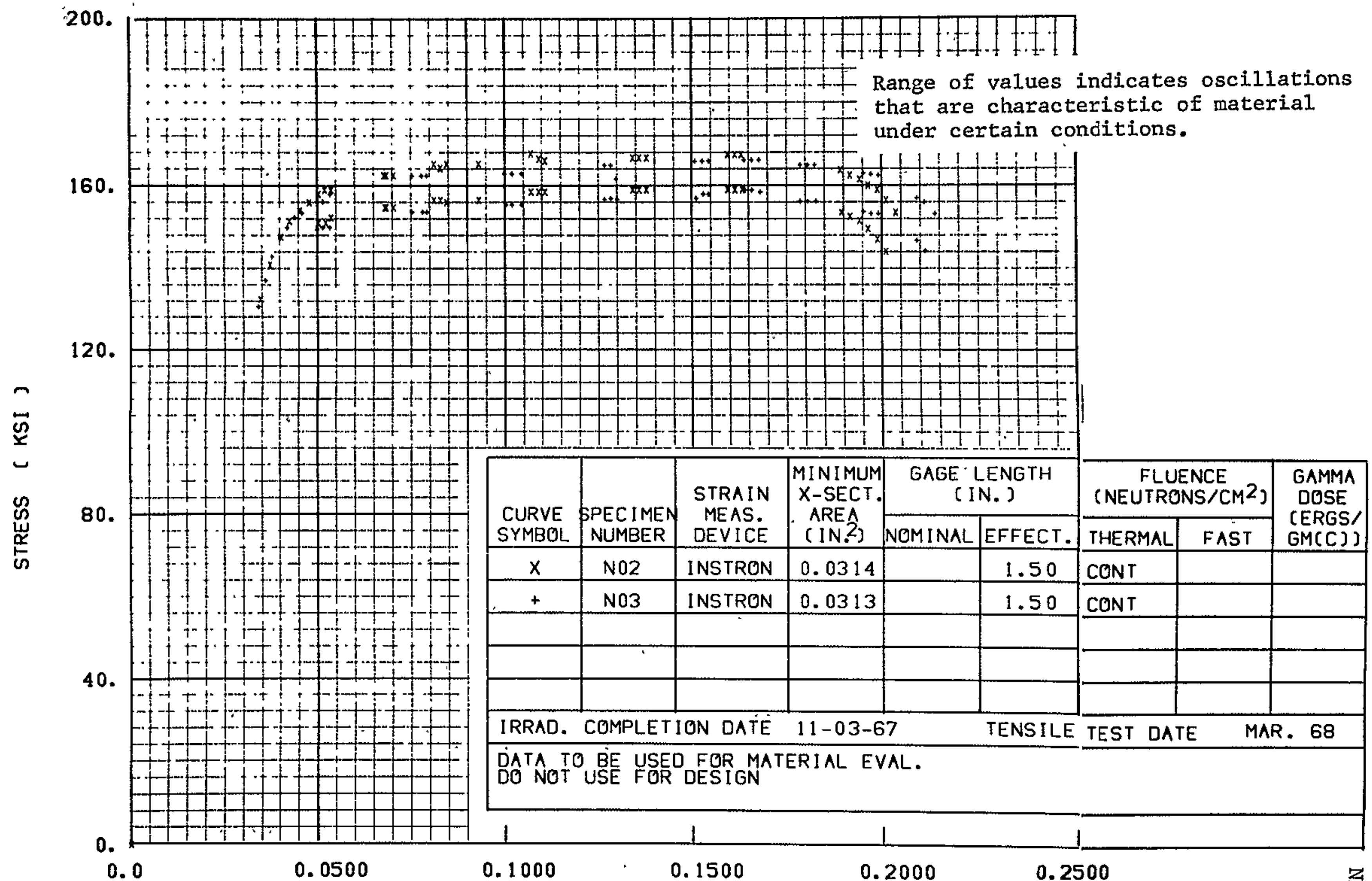
IRRAD. COMPLETION DATE 11-03-67 TENSILE TEST DATE MAR. 68

DATA TO BE USED FOR MATERIAL EVAL.
DO NOT USE FOR DESIGN

STRAIN (IN./IN. OF GAGE LENGTH)(BASED ON HANDBOOK MODULUS)

FIGURE 6-48 STRESS-STRAIN CURVES FOR INCONEL 718(.6 PPM B).
HIGH IRRAD. 1660 R (0.0013 IN./IN./MIN). FITTED TO HDBK MOD

NPC 26,879



CURVE SYMBOL	SPECIMEN NUMBER	STRAIN MEAS. DEVICE	MINIMUM X-SECT. AREA (IN.^{2})	GAGE LENGTH (IN.) NOMINAL	GAGE LENGTH (IN.) EFFECT.	FLUENCE (NEUTRONS/CM^2) THERMAL	FLUENCE (NEUTRONS/CM^2) FAST	GAMMA DOSE (ERGS/GM(C))
X	N02	INSTRON	0.0314		1.50	CONT		
+	N03	INSTRON	0.0313		1.50	CONT		

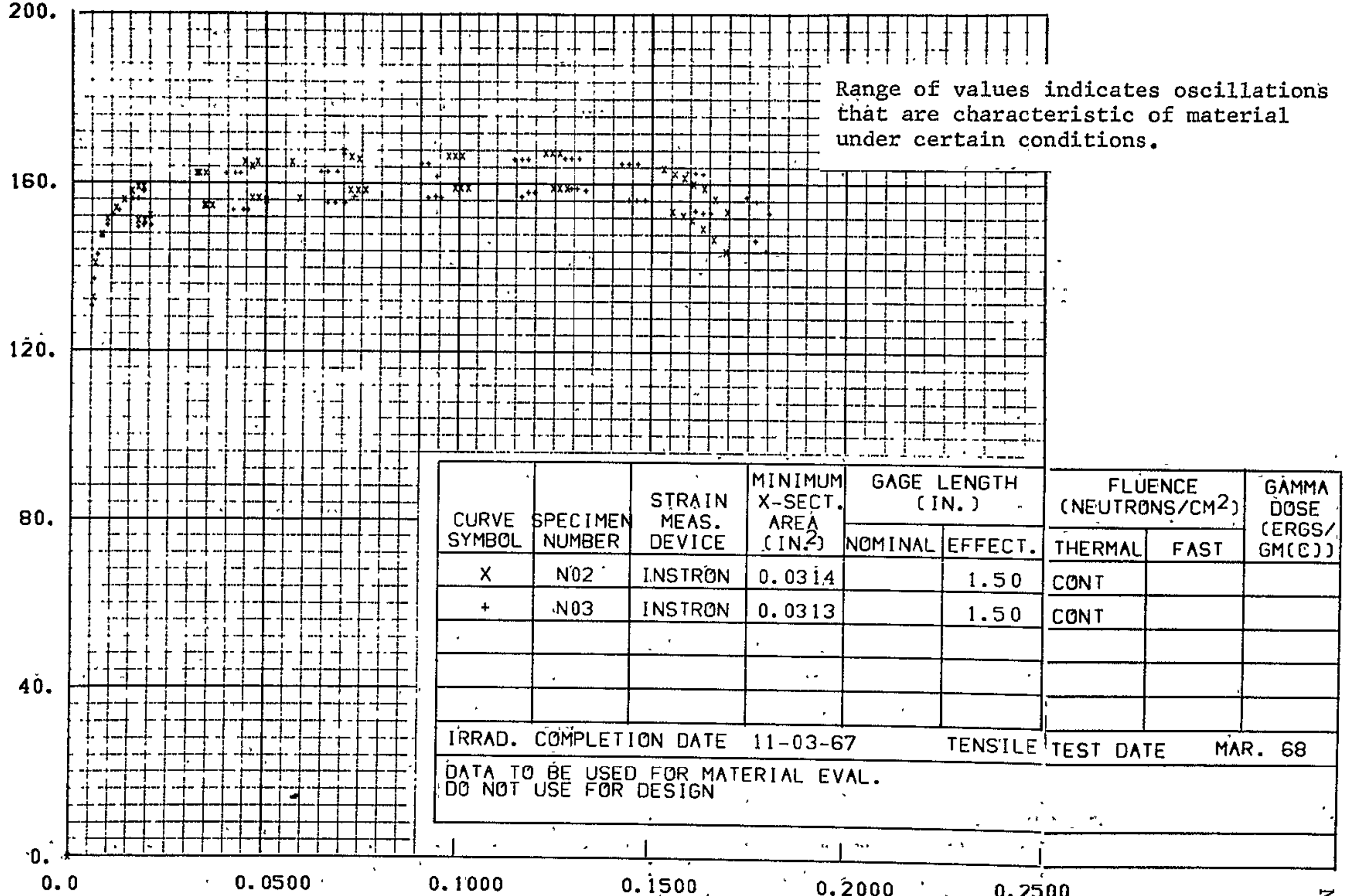
IRRAD. COMPLETION DATE 11-03-67 TENSILE TEST DATE MAR. 68

DATA TO BE USED FOR MATERIAL EVAL.
DO NOT USE FOR DESIGN

STRAIN (IN./IN. OF GAGE LENGTH)(BASED ON CROSSHEAD TRAVEL)

FIGURE 6-49 STRESS-STRAIN CURVES FOR INCONEL 718(37 PPM B). CONTROLS. TESTED AT 1360 R (0.0013 IN./IN./MIN)

NPC 26,880



CURVE SYMBOL	SPECIMEN NUMBER	STRAIN MEAS. DEVICE	MINIMUM X-SECT. AREA (IN.^{2})	GAGE LENGTH (IN.) NOMINAL	GAGE LENGTH (IN.) EFFECT.	FLUENCE (NEUTRONS/CM^2) THERMAL	FLUENCE (NEUTRONS/CM^2) FAST	GAMMA DOSE (ERGS/GM(C))
X	N02	INSTRON	0.0314		1.50	CONT		
+	N03	INSTRON	0.0313		1.50	CONT		

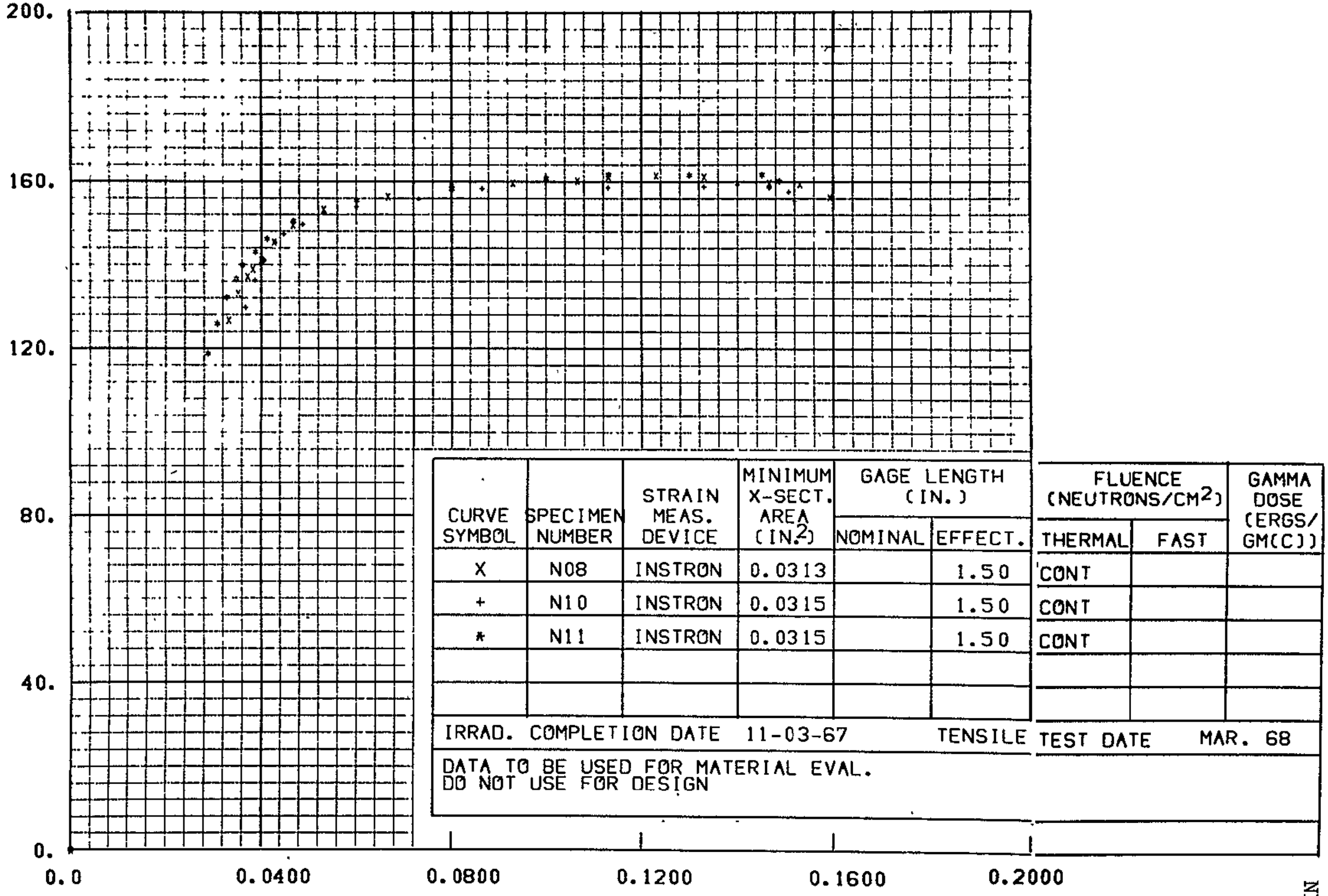
IRRAD. COMPLETION DATE 11-03-67 TENSILE TEST DATE MAR. 68

DATA TO BE USED FOR MATERIAL EVAL.
DO NOT USE FOR DESIGN

STRAIN (IN./IN. OF GAGE LENGTH)(BASED ON HANDBOOK MODULUS)

FIGURE 6-50 STRESS-STRAIN CURVES FOR INCONEL 718(37 PPM B). CONTROLS. 1360 R (0.0013 IN./IN./MIN). FITTED TO HDBK MOD

NPC 26,881



CURVE SYMBOL	SPECIMEN NUMBER	STRAIN MEAS. DEVICE	MINIMUM X-SECT. AREA (IN.^{2})	GAGE LENGTH (IN.) NOMINAL	GAGE LENGTH (IN.) EFFECT.	FLUENCE (NEUTRONS/CM^2) THERMAL	FLUENCE (NEUTRONS/CM^2) FAST	GAMMA DOSE (ERGS/GM(C))
X	N08	INSTRON	0.0313		1.50	CONT		
+	N10	INSTRON	0.0315		1.50	CONT		
*	N11	INSTRON	0.0315		1.50	CONT		

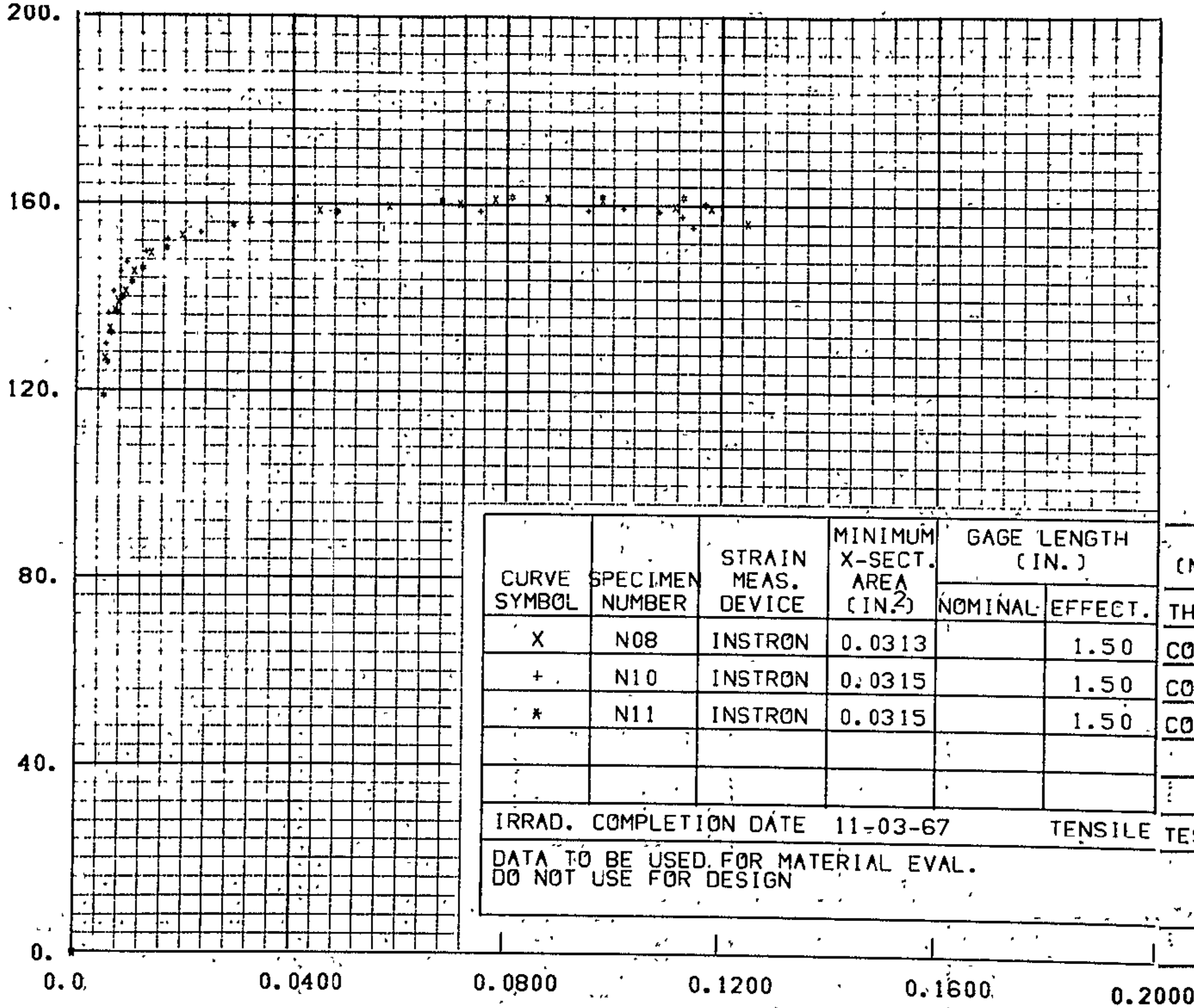
IRRAD. COMPLETION DATE 11-03-67 TENSILE TEST DATE MAR. 68

DATA TO BE USED FOR MATERIAL EVAL.
DO NOT USE FOR DESIGN

STRAIN (IN./IN. OF GAGE LENGTH)(BASED ON CROSSHEAD TRAVEL)

FIGURE 6-51 STRESS-STRAIN CURVES FOR INCONEL 718(37 PPM B). CONTROLS. TESTED AT 1510 R (0.0013 IN./IN./MIN)

NPC 26,882



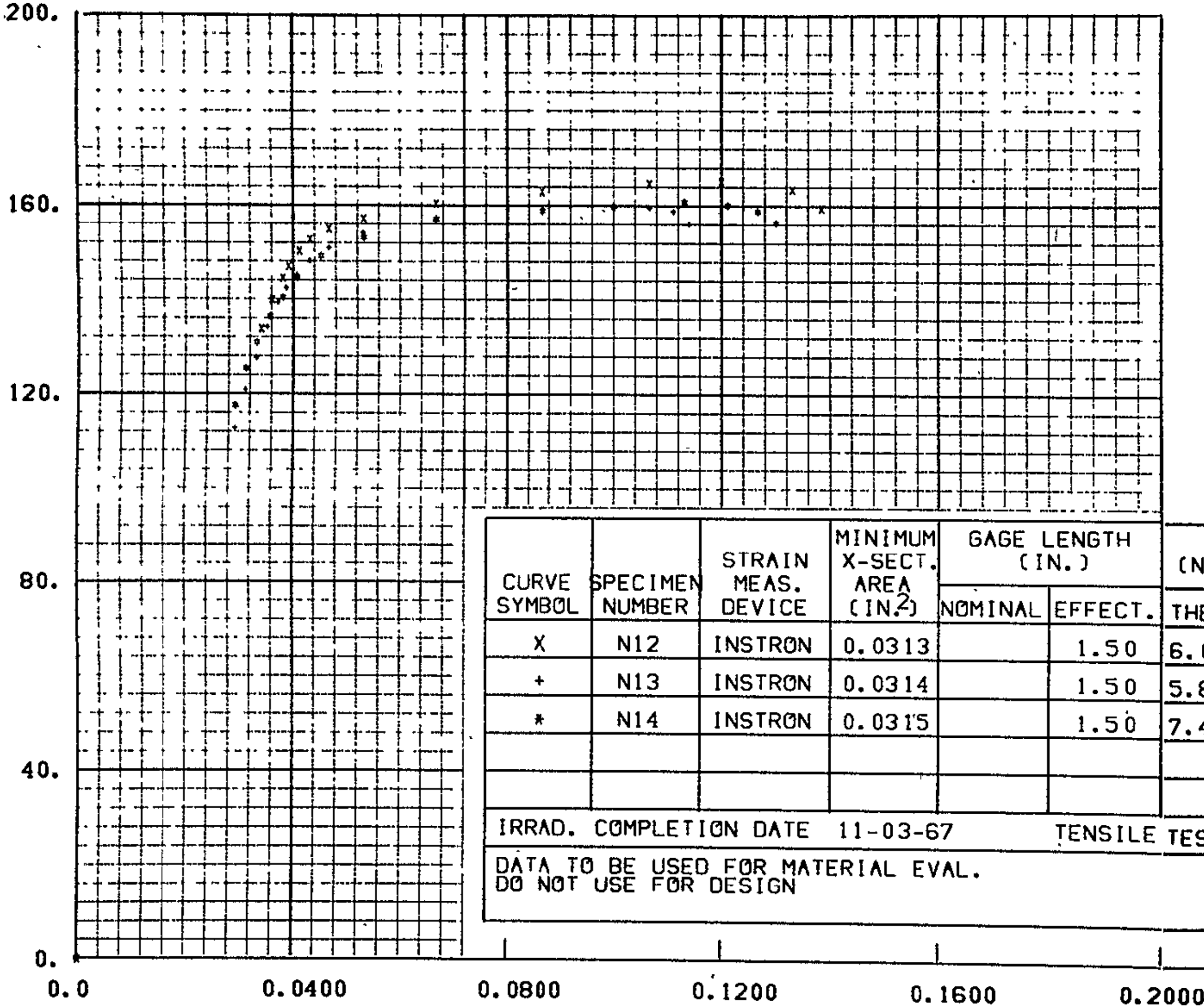
CURVE SYMBOL	SPECIMEN NUMBER	STRAIN MEAS. DEVICE	MINIMUM X-SECT. AREA ($IN.^2$)	GAGE LENGTH (IN.) NOMINAL	GAGE LENGTH (IN.) EFFECT.	FLUENCE ($NEUTRONS/CM^2$) THERMAL	FLUENCE ($NEUTRONS/CM^2$) FAST	GAMMA DOSE (ERGS/GM(C))
X	N08	INSTRON	0.0313		1.50	CONT		
+	N10	INSTRON	0.0315		1.50	CONT		
*	N11	INSTRON	0.0315		1.50	CONT		

IRRAD. COMPLETION DATE 11-03-67 TENSILE TEST DATE MAR. 68

DATA TO BE USED FOR MATERIAL EVAL.
DO NOT USE FOR DESIGN

FIGURE 6-52 STRESS-STRAIN CURVES FOR INCONEL 718(37 PPM B).
CONTROLS: 1510 R (0.0013 IN./IN./MIN), FITTED TO HDBK MOD

NPC 26,883



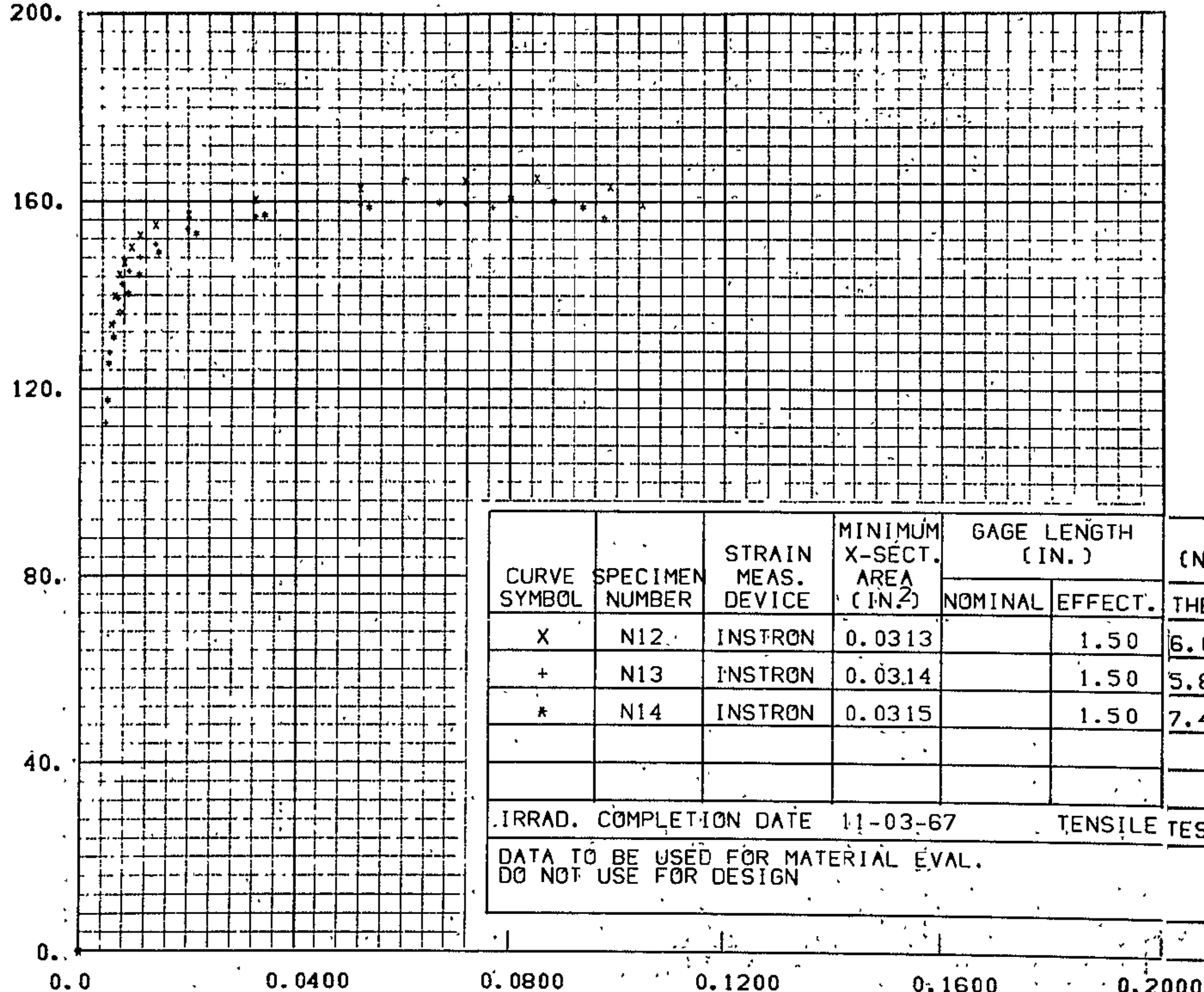
CURVE SYMBOL	SPECIMEN NUMBER	STRAIN MEAS. DEVICE	MINIMUM X-SECT. AREA ($IN.^2$)	GAGE LENGTH (IN.) NOMINAL	GAGE LENGTH (IN.) EFFECT.	FLUENCE (NEUTRONS/CM^2) THERMAL	FLUENCE (NEUTRONS/CM^2) FAST	GAMMA DOSE (ERGS/GM(C))
X	N12	INSTRON	0.0313		1.50	6.0+15	3.4+15	1.9+11
+	N13	INSTRON	0.0314		1.50	5.8+15	3.3+15	1.9+11
*	N14	INSTRON	0.0315		1.50	7.4+15	4.3+15	2.0+11

IRRAD. COMPLETION DATE 11-03-67 TENSILE TEST DATE MAR. 68

DATA TO BE USED FOR MATERIAL EVAL.
DO NOT USE FOR DESIGN

FIGURE 6-53 STRESS-STRAIN CURVES FOR INCONEL 718(37 PPM B).
LOW IRRAD. TESTED AT 1510 R (0.0013 IN./IN./MIN)

NPC 26,884



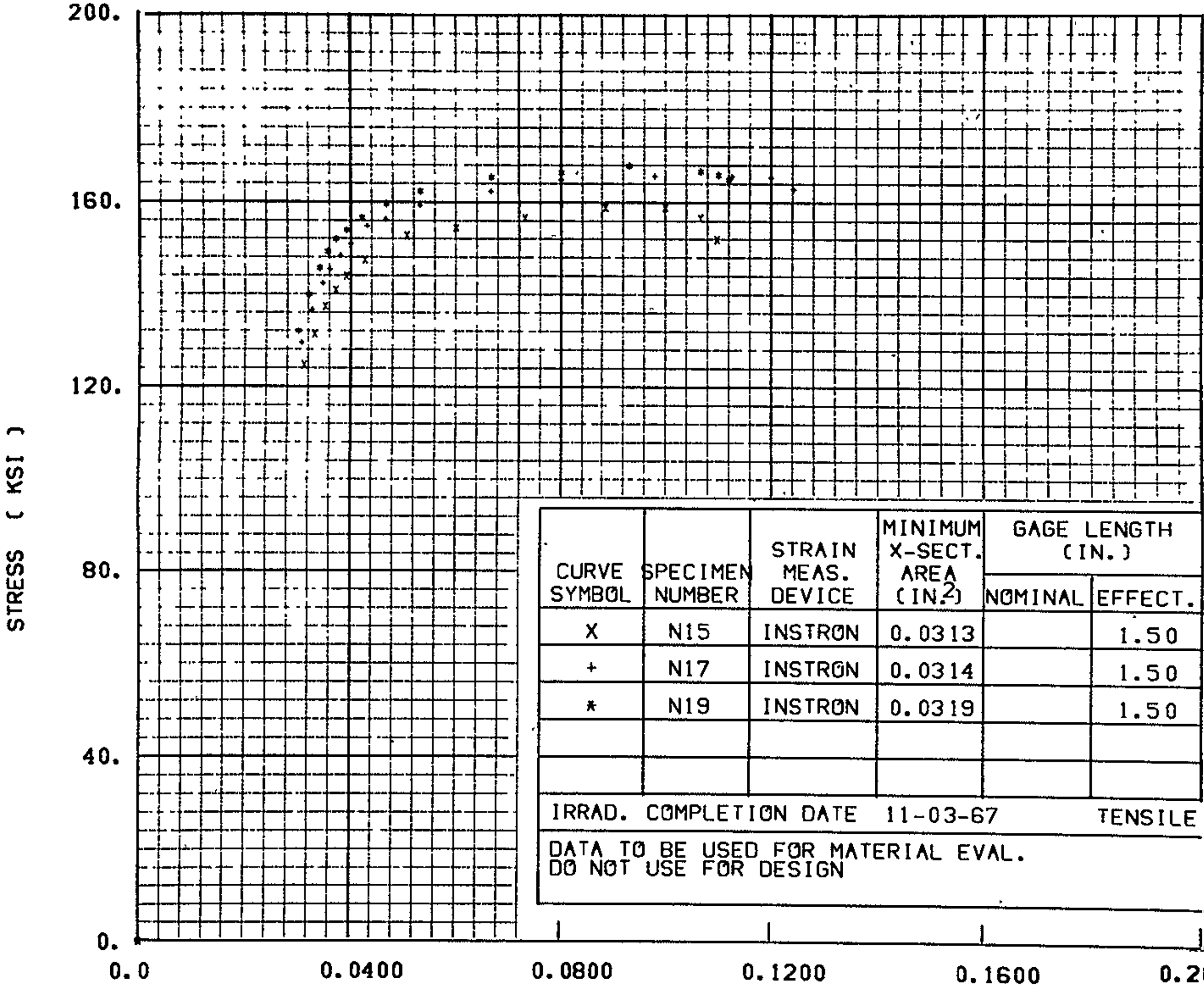
CURVE SYMBOL	SPECIMEN NUMBER	STRAIN MEAS. DEVICE	MINIMUM X-SECT. AREA (IN.^{2})	GAGE LENGTH (IN.)		FLUENCE (NEUTRONS/CM^2)		GAMMA DOSE (ERGS/GM(C))
				NOMINAL	EFFECT.	THERMAL	FAST.	
X	N12	INSTRON	0.0313		1.50	6.0+15	3.4+15	1.9+11
+	N13	INSTRON	0.0314		1.50	5.8+15	3.3+15	1.9+11
*	N14	INSTRON	0.0315		1.50	7.4+15	4.3+15	2.0+11

IRRAD. COMPLETION DATE 11-03-67 TENSILE TEST DATE MAR. 68

DATA TO BE USED FOR MATERIAL EVAL.
DO NOT USE FOR DESIGN

FIGURE 6-54 STRESS-STRAIN CURVES FOR INCONEL 718(37 PPM B).
LOW IRRAD. 1510 R (0.0013 IN./IN./MIN). FITTED TO WORK MOD

NPC 26,885



CURVE SYMBOL	SPECIMEN NUMBER	STRAIN MEAS. DEVICE	MINIMUM X-SECT. AREA (IN.^{2})	GAGE LENGTH (IN.) NOMINAL	GAGE LENGTH (IN.) EFFECT.	FLUENCE (NEUTRONS/CM^2) THERMAL	FLUENCE (NEUTRONS/CM^2) FAST	GAMMA DOSE (ERGS/GM(C))
X	N15	INSTRON	0.0313		1.50	1.4+17	5.5+16	7.6+11
+	N17	INSTRON	0.0314		1.50	1.3+17	5.2+16	7.4+11
*	N19	INSTRON	0.0319		1.50	1.4+17	6.6+16	7.5+11

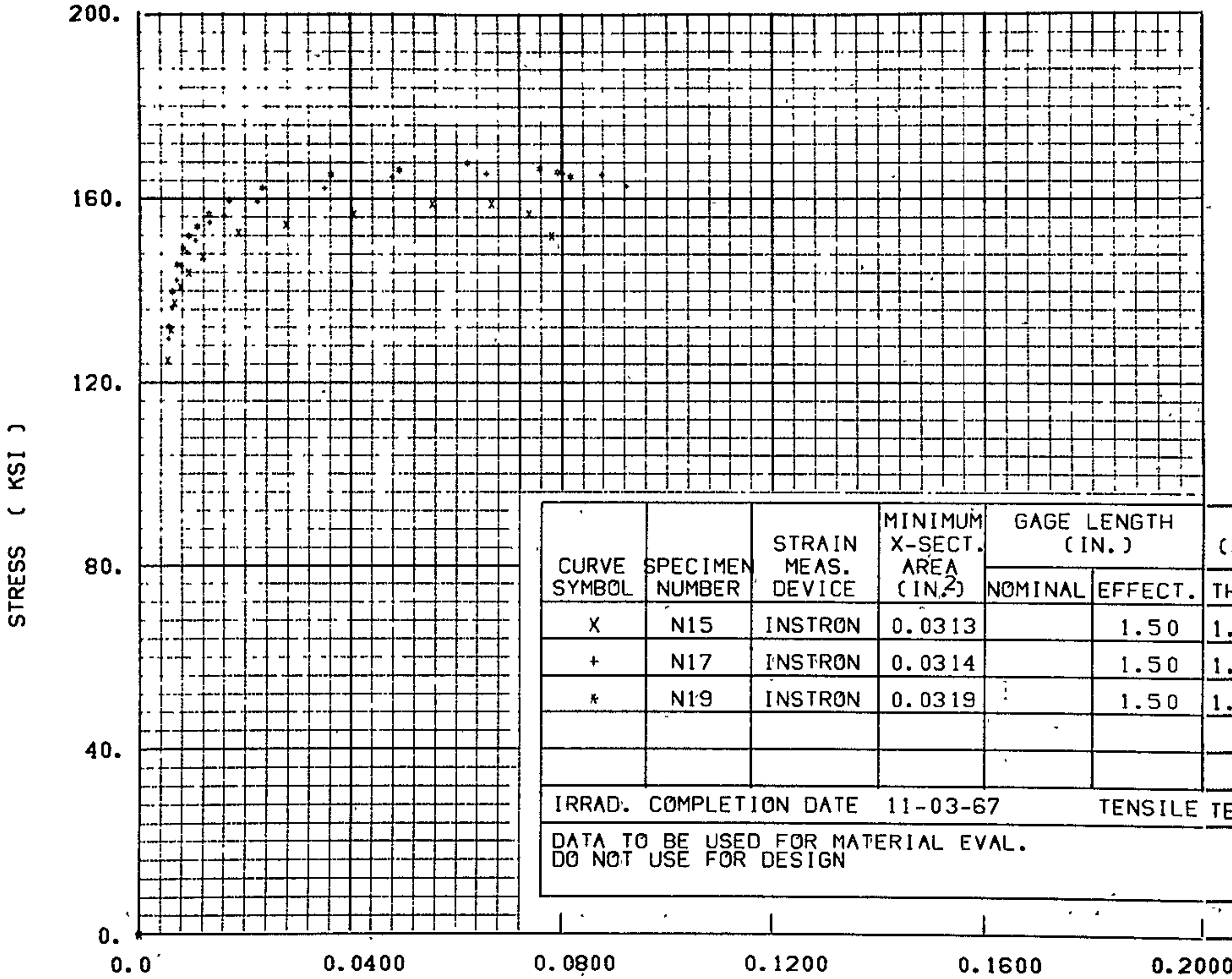
IRRAD. COMPLETION DATE 11-03-67 TENSILE TEST DATE MAR. 68

DATA TO BE USED FOR MATERIAL EVAL.
DO NOT USE FOR DESIGN

STRAIN (IN./IN. OF GAGE LENGTH)(BASED ON CROSSHEAD TRAVEL)

FIGURE 6-55 STRESS-STRAIN CURVES FOR INCONEL 718(37 PPM B).
MED IRRAD. TESTED AT 1510 R (0.0013 IN./IN./MIN)

NPC 26,886



CURVE SYMBOL	SPECIMEN NUMBER	STRAIN MEAS. DEVICE	MINIMUM X-SECT. AREA (IN.^{2})	GAGE LENGTH (IN.) NOMINAL	GAGE LENGTH (IN.) EFFECT.	FLUENCE (NEUTRONS/CM^2) THERMAL	FLUENCE (NEUTRONS/CM^2) FAST	GAMMA DOSE (ERGS/GM(C))
X	N15	INSTRON	0.0313		1.50	1.4+17	5.5+16	7.6+11
+	N17	INSTRON	0.0314		1.50	1.3+17	5.2+16	7.4+11
*	N19	INSTRON	0.0319		1.50	1.4+17	6.6+16	7.5+11

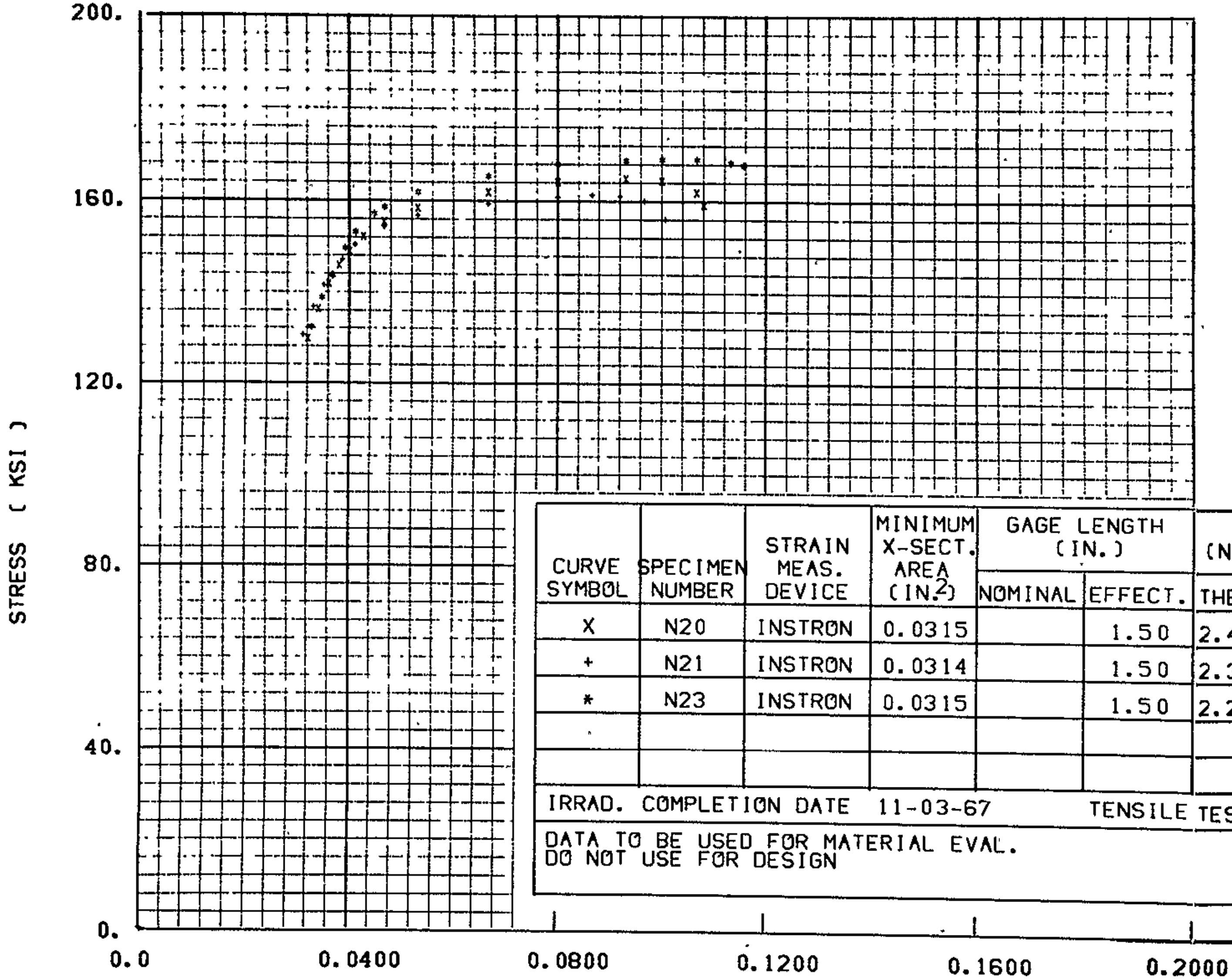
IRRAD. COMPLETION DATE 11-03-67 TENSILE TEST DATE MAR. 68

DATA TO BE USED FOR MATERIAL EVAL.
DO NOT USE FOR DESIGN

STRAIN (IN./IN. OF GAGE LENGTH)(BASED ON HANDBOOK MODULUS)

FIGURE 6-56 STRESS-STRAIN CURVES FOR INCONEL 718(37 PPM B).
MED IRRAD. 1510 R (0.0013 IN./IN./MIN), FITTED TO HDBK MOD

NPC 26,887

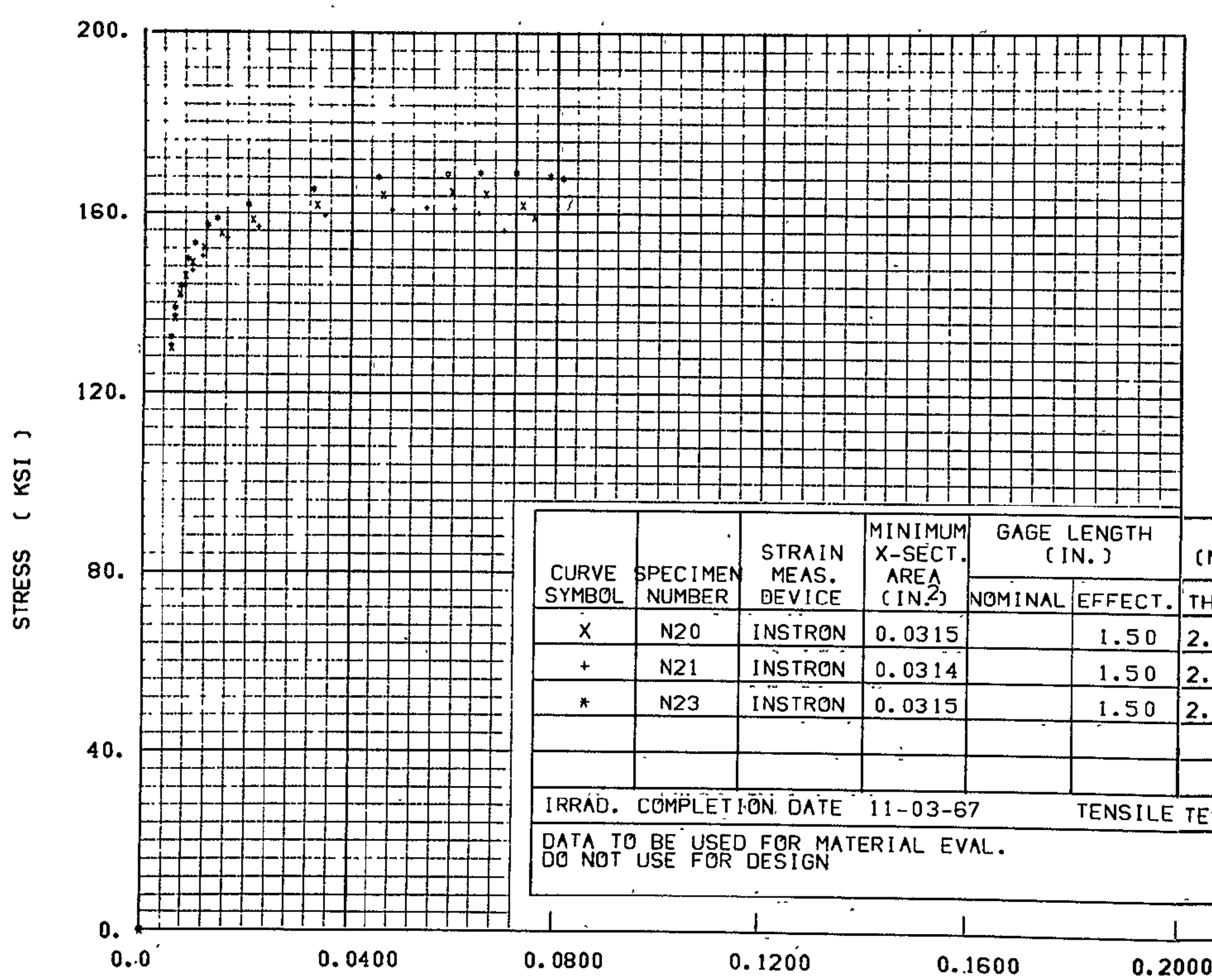


CURVE SYMBOL	SPECIMEN NUMBER	STRAIN MEAS. DEVICE	MINIMUM X-SECT. AREA (IN.^{2})	GAGE LENGTH (IN.) NOMINAL	GAGE LENGTH (IN.) EFFECT.	FLUENCE (NEUTRONS/CM^2) THERMAL	FLUENCE (NEUTRONS/CM^2) FAST	GAMMA DOSE (ERGS/GM(C))
X	N20	INSTRON	0.0315		1.50	2.4+18	6.6+17	2.4+12
+	N21	INSTRON	0.0314		1.50	2.3+18	6.5+17	2.4+12
*	N23	INSTRON	0.0315		1.50	2.2+18	6.4+17	2.3+12

IRRAD. COMPLETION DATE 11-03-67 TENSILE TEST DATE MAR. 68

DATA TO BE USED FOR MATERIAL EVAL.
DO NOT USE FOR DESIGN

FIGURE 6-57 STRESS-STRAIN CURVES FOR INCONEL 718(37 PPM.B).
HIGH IRRAD. TESTED AT 1510 R (0.0013 IN./IN./MIN)



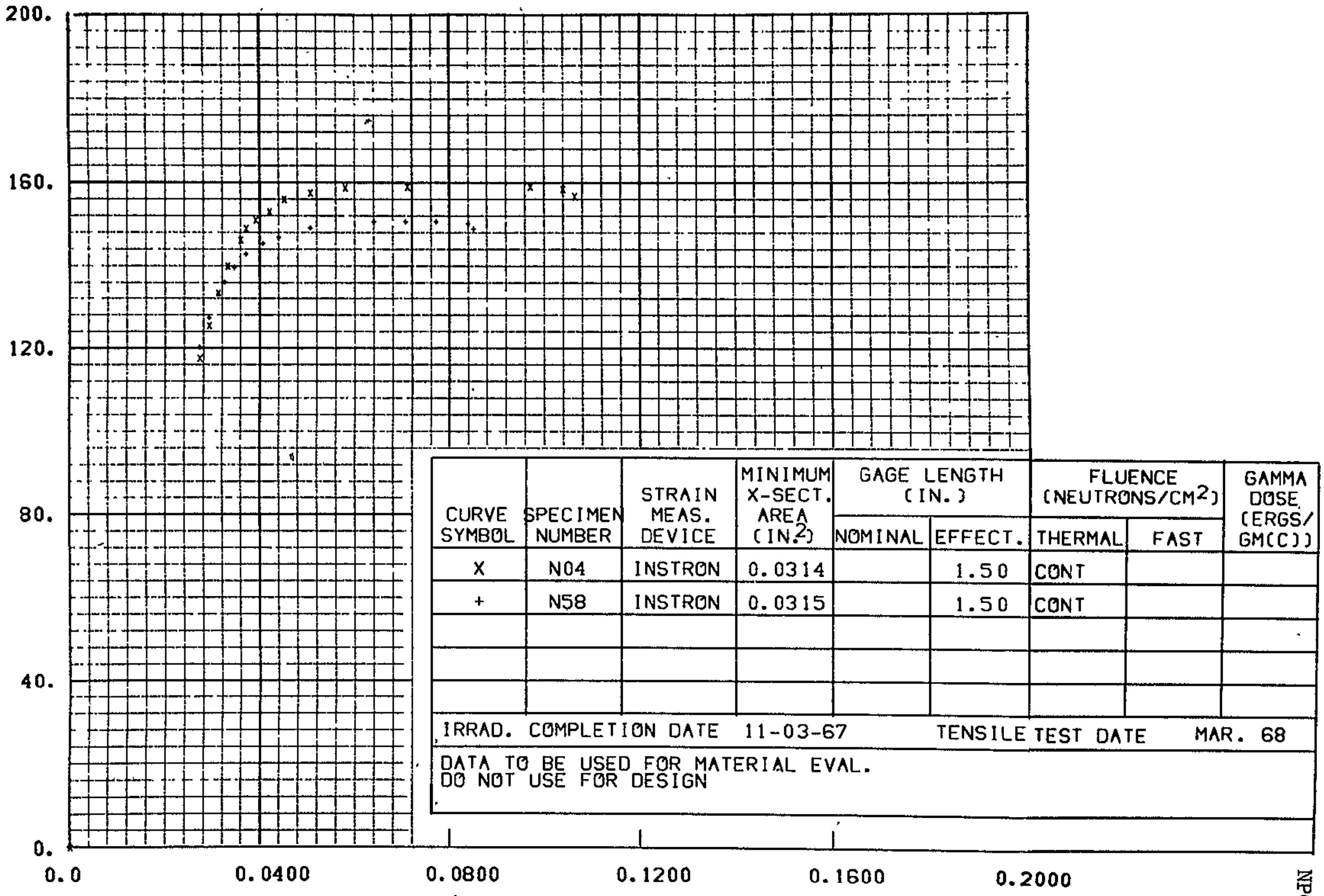
CURVE SYMBOL	SPECIMEN NUMBER	STRAIN MEAS. DEVICE	MINIMUM X-SECT. AREA (IN.^{2})	GAGE LENGTH (IN.) NOMINAL	GAGE LENGTH (IN.) EFFECT.	FLUENCE (NEUTRONS/CM^2) THERMAL	FLUENCE (NEUTRONS/CM^2) FAST	GAMMA DOSE (ERGS/GM(C))
X	N20	INSTRON	0.0315		1.50	2.4+18	6.6+17	2.4+12
+	N21	INSTRON	0.0314		1.50	2.3+18	6.5+17	2.4+12
*	N23	INSTRON	0.0315		1.50	2.2+18	6.4+17	2.3+12

IRRAD. COMPLETION DATE 11-03-67 TENSILE TEST DATE MAR. 68

DATA TO BE USED FOR MATERIAL EVAL.
DO NOT USE FOR DESIGN

FIGURE 6-58 STRESS-STRAIN CURVES FOR INCONEL 718(37 PPM B).
HIGH IRRAD, 1510 R (0.0013 IN./IN./MIN), FITTED TO HDBK MOD

NPC 26,889



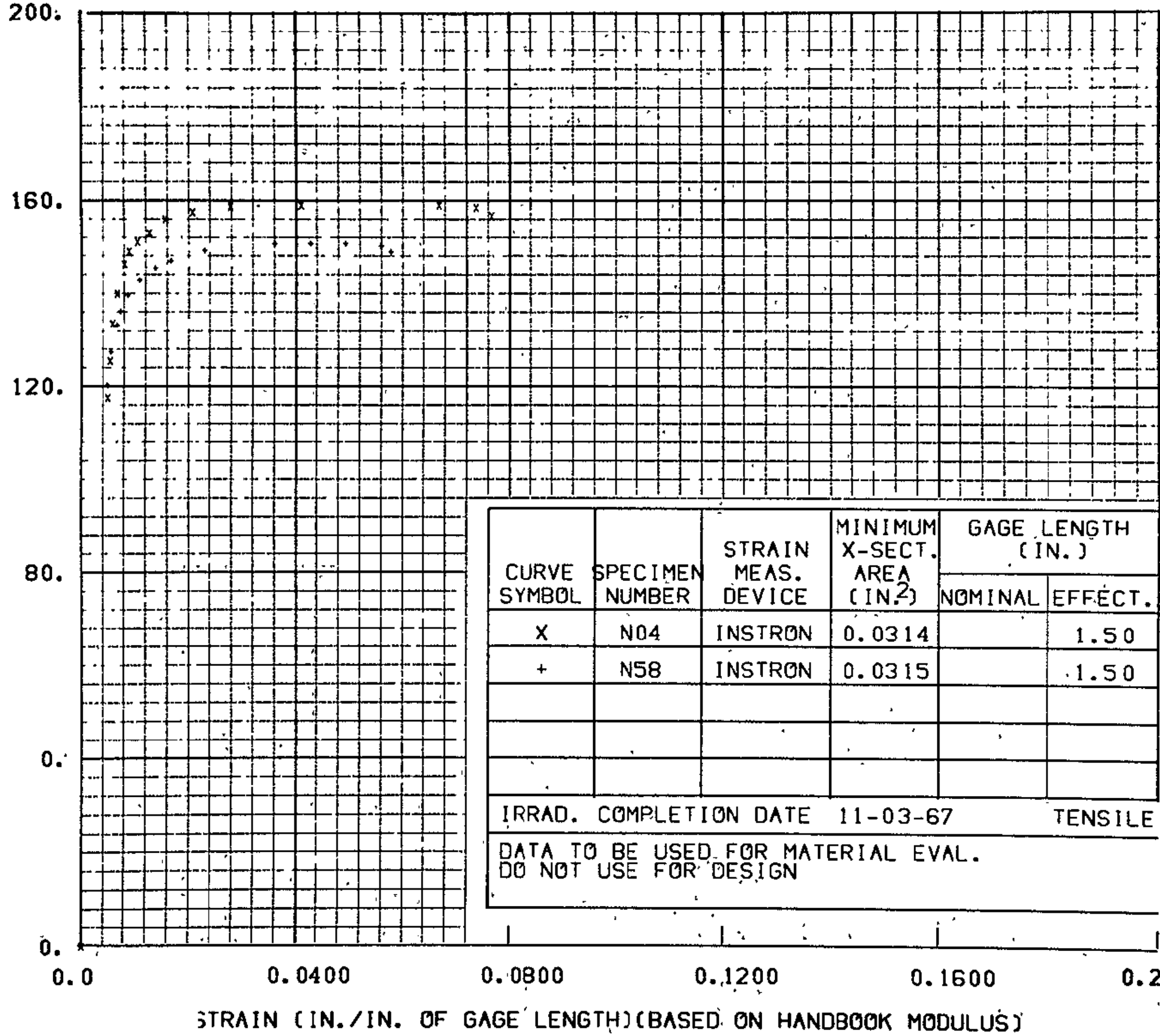
CURVE SYMBOL	SPECIMEN NUMBER	STRAIN MEAS. DEVICE	MINIMUM X-SECT. AREA ($IN.^2$)	GAGE LENGTH (IN.) NOMINAL	GAGE LENGTH (IN.) EFFECT.	FLUENCE ($NEUTRONS/CM^2$) THERMAL	FLUENCE ($NEUTRONS/CM^2$) FAST	GAMMA DOSE (ERGS/ GM(C))
X	N04	INSTRON	0.0314		1.50	CONT		
+	N58	INSTRON	0.0315		1.50	CONT		

IRRAD. COMPLETION DATE 11-03-67 TENSILE TEST DATE MAR. 68

DATA TO BE USED FOR MATERIAL EVAL.
DO NOT USE FOR DESIGN

FIGURE 6-59 STRESS-STRAIN CURVES FOR INCONEL 718(37 PPM B).
CONTROLS. TESTED AT 1575 R (0.0013 IN./IN./MIN)

NPC 26,890



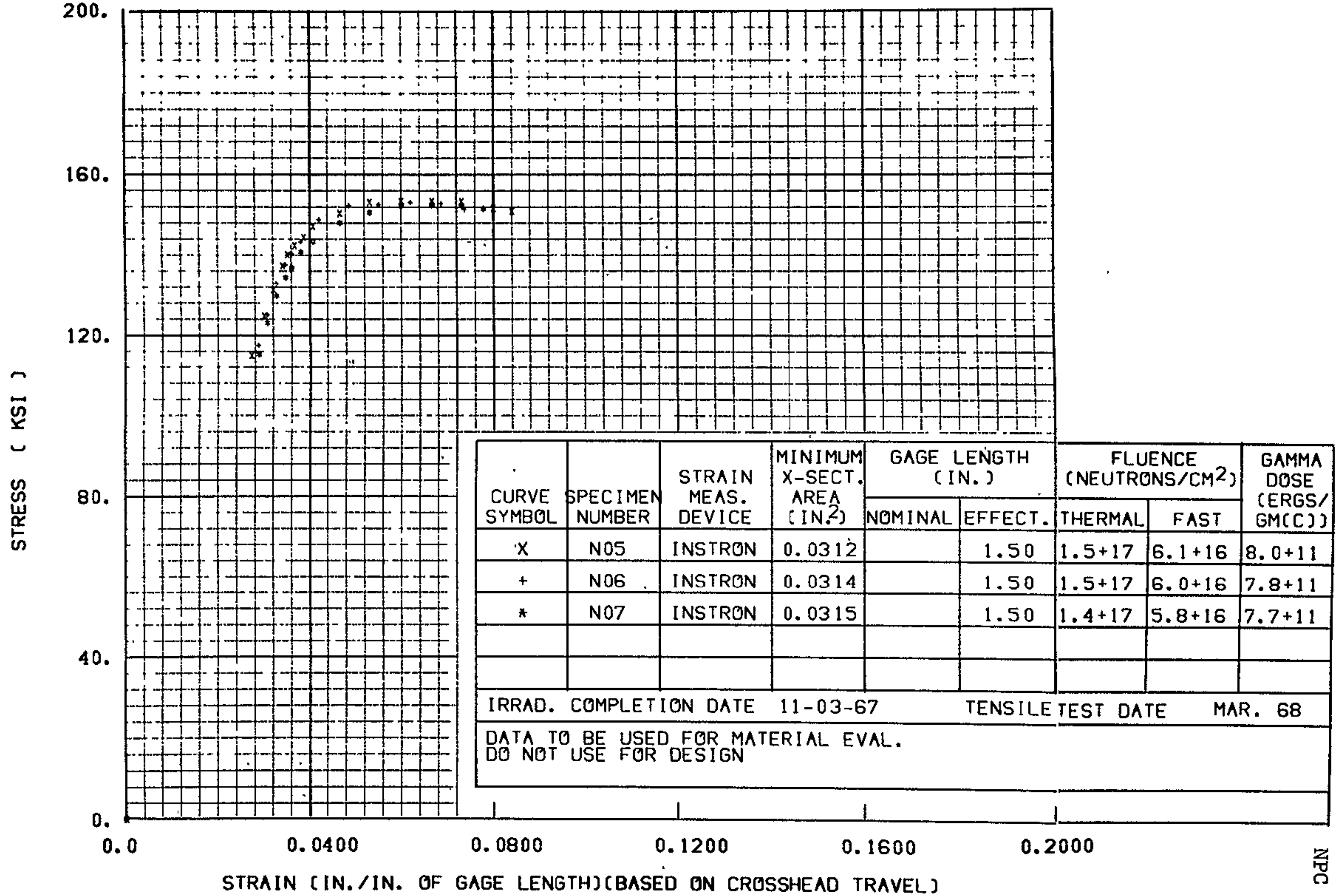
CURVE SYMBOL	SPECIMEN NUMBER	STRAIN MEAS. DEVICE	MINIMUM X-SECT. AREA (IN.^{2})	GAGE LENGTH (IN.) NOMINAL	GAGE LENGTH (IN.) EFFECT.	FLUENCE (NEUTRONS/CM^2) THERMAL	FLUENCE (NEUTRONS/CM^2) FAST	GAMMA DOSE (ERGS/GM(C))
X	N04	INSTRON	0.0314		1.50	CONT		
+	N58	INSTRON	0.0315		1.50	CONT		

IRRAD. COMPLETION DATE 11-03-67 TENSILE TEST DATE MAR. 68

DATA TO BE USED FOR MATERIAL EVAL.
DO NOT USE FOR DESIGN

FIGURE 6-60 STRESS-STRAIN CURVES FOR INCONEL 718(37 PPM B).
CONTROLS. 1575 R (0.0013 IN./IN./MIN). FITTED TO WORK MOD

NPC 26,891



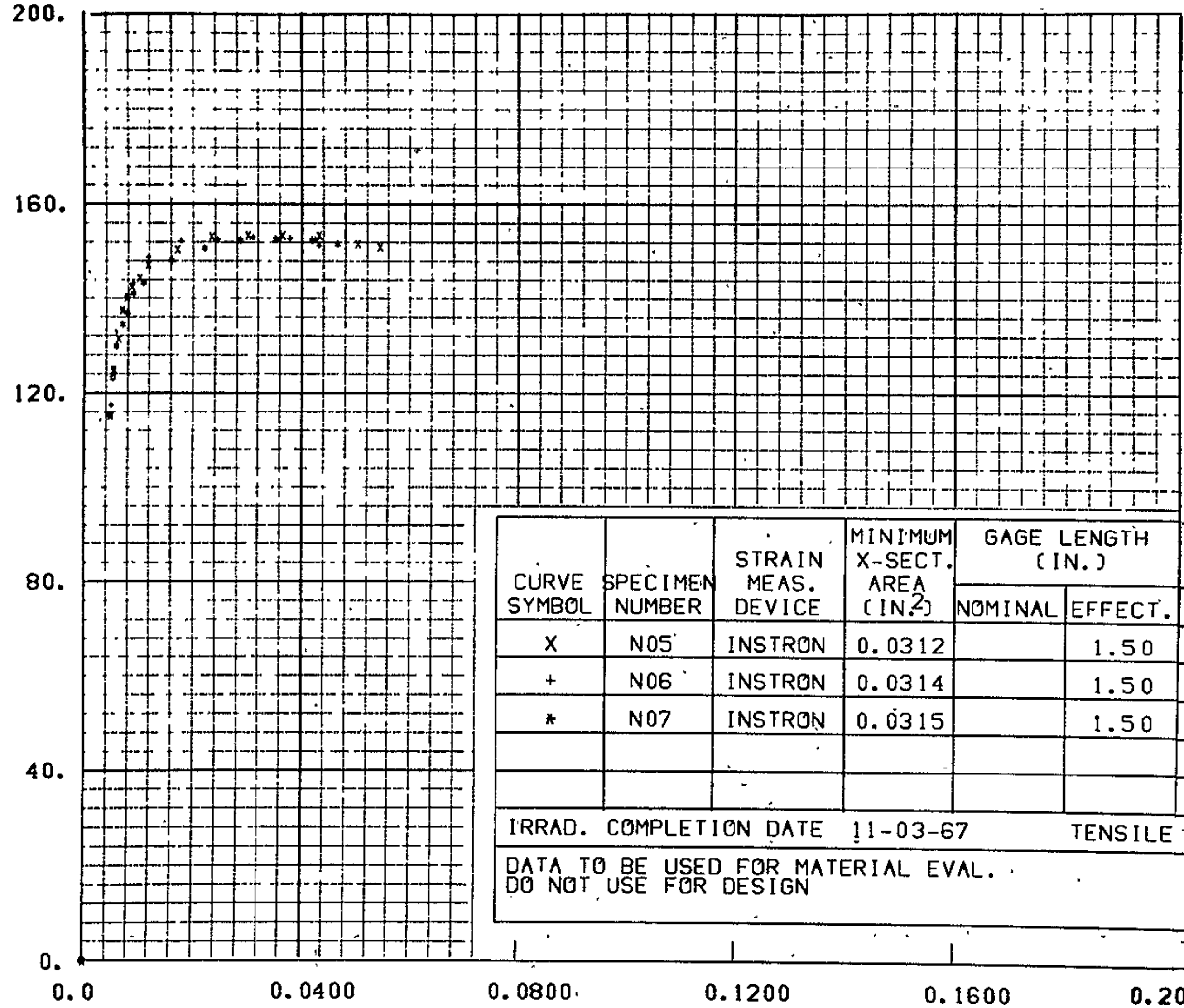
CURVE SYMBOL	SPECIMEN NUMBER	STRAIN MEAS. DEVICE	MINIMUM X-SECT. AREA (IN.^{2})	GAGE LENGTH (IN.) NOMINAL	GAGE LENGTH (IN.) EFFECT.	FLUENCE (NEUTRONS/CM^2) THERMAL	FLUENCE (NEUTRONS/CM^2) FAST	GAMMA DOSE (ERGS/GM(C))
X	N05	INSTRON	0.0312		1.50	1.5+17	6.1+16	8.0+11
+	N06	INSTRON	0.0314		1.50	1.5+17	6.0+16	7.8+11
*	N07	INSTRON	0.0315		1.50	1.4+17	5.8+16	7.7+11

IRRAD. COMPLETION DATE 11-03-67 TENSILE TEST DATE MAR. 68

DATA TO BE USED FOR MATERIAL EVAL.
DO NOT USE FOR DESIGN

FIGURE 6-61 STRESS-STRAIN CURVES FOR INCONEL 718(37 PPM B).
MED IRRAD. TESTED AT 1575 R (0.0013 IN./IN./MIN)

NPC 26,892



CURVE SYMBOL	SPECIMEN NUMBER	STRAIN MEAS. DEVICE	MINIMUM X-SECT. AREA (IN.^{2})	GAGE LENGTH (IN.) NOMINAL	GAGE LENGTH (IN.) EFFECT.	FLUENCE (NEUTRONS/CM^2) THERMAL	FLUENCE (NEUTRONS/CM^2) FAST	GAMMA DOSE (ERGS/ GM(C))
X	N05	INSTRON	0.0312		1.50	1.5+17	6.1+16	8.0+11
+	N06	INSTRON	0.0314		1.50	1.5+17	6.0+16	7.8+11
*	N07	INSTRON	0.0315		1.50	1.4+17	5.8+16	7.7+11

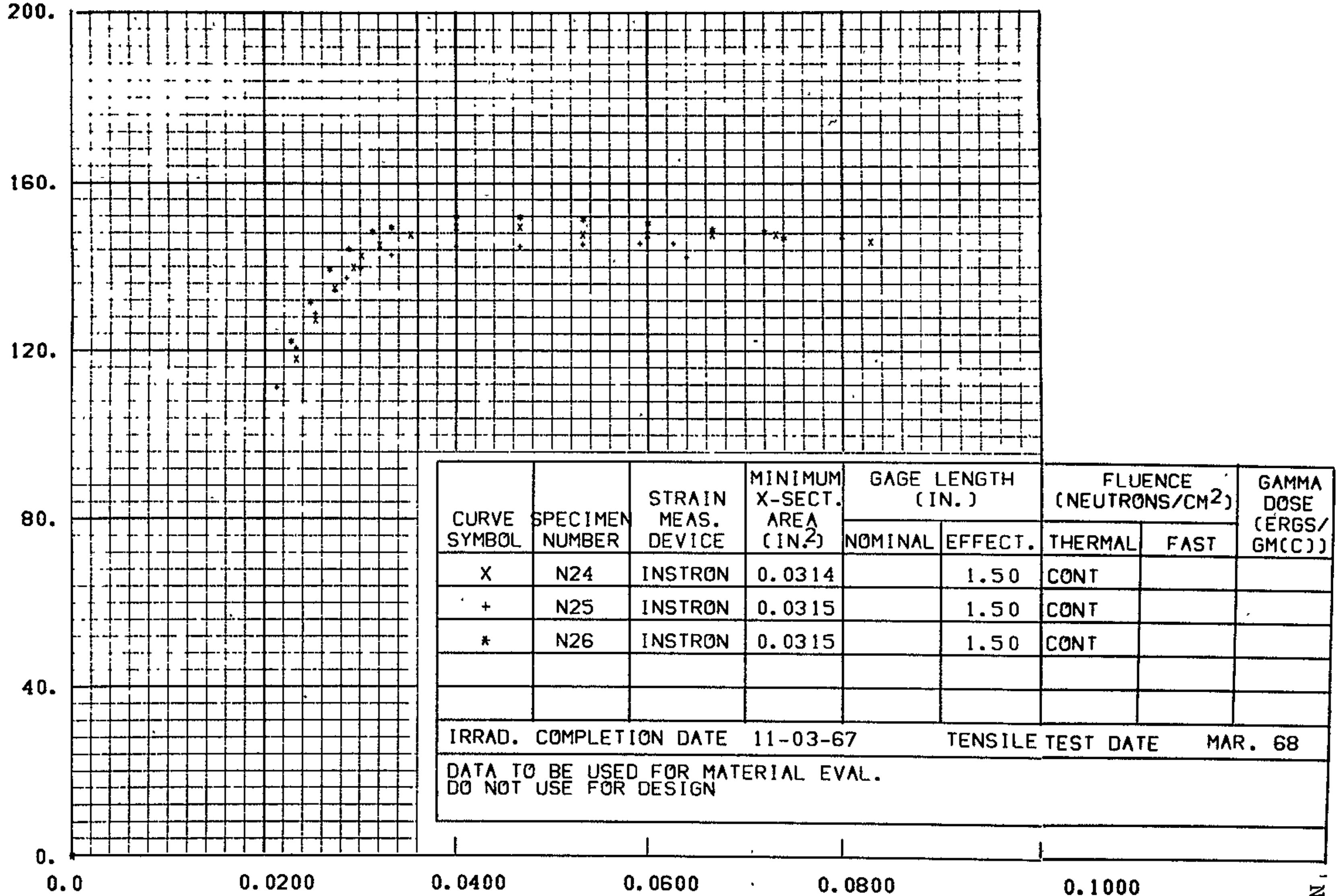
IRRAD. COMPLETION DATE 11-03-67 TENSILE TEST DATE MAR. 68

DATA TO BE USED FOR MATERIAL EVAL.
DO NOT USE FOR DESIGN

STRAIN (IN./IN. OF GAGE LENGTH)(BASED ON HANDBOOK MODULUS)

FIGURE 6-62 STRESS-STRAIN CURVES FOR INCONEL 718(37 PPM B).
MED IRRAD. 1575 R (0.0013 IN./IN./MIN), FITTED TO HDBK MOD

NPC 26,893



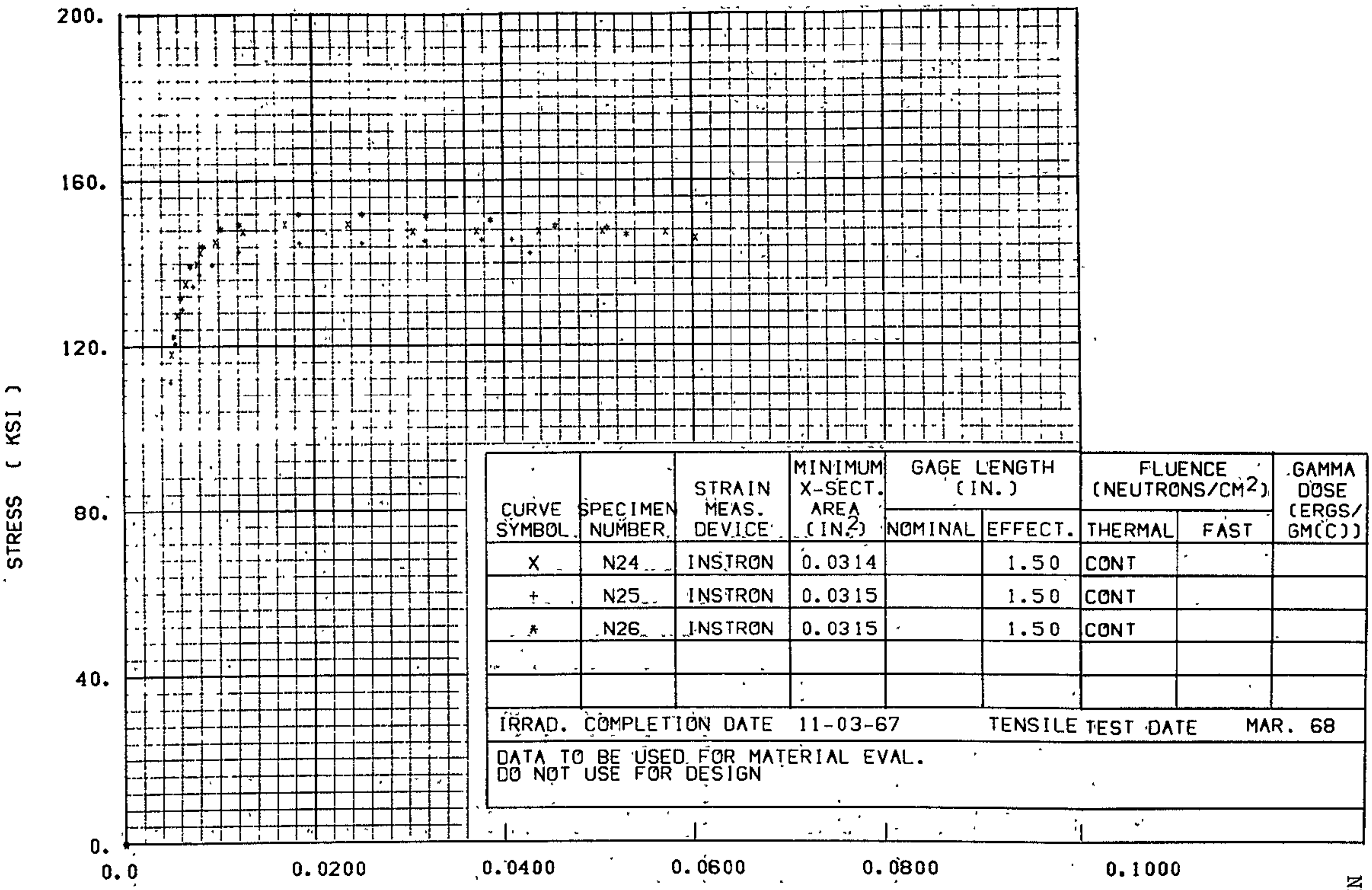
CURVE SYMBOL	SPECIMEN NUMBER	STRAIN MEAS. DEVICE	MINIMUM X-SECT. AREA ($IN.^2$)	GAGE LENGTH (IN.) NOMINAL	GAGE LENGTH (IN.) EFFECT.	FLUENCE ($NEUTRONS/CM^2$) THERMAL	FLUENCE ($NEUTRONS/CM^2$) FAST	GAMMA DOSE (ERGS/GM(C))
X	N24	INSTRON	0.0314		1.50	CONT		
+	N25	INSTRON	0.0315		1.50	CONT		
*	N26	INSTRON	0.0315		1.50	CONT		

IRRAD. COMPLETION DATE 11-03-67 TENSILE TEST DATE MAR. 68

DATA TO BE USED FOR MATERIAL EVAL.
DO NOT USE FOR DESIGN

FIGURE 6-63 STRESS-STRAIN CURVES FOR INCONEL 718(37 PPM B).
CONTROLS. TESTED AT 1660 R (0.0013 IN./IN./MIN)

NPC 26,894



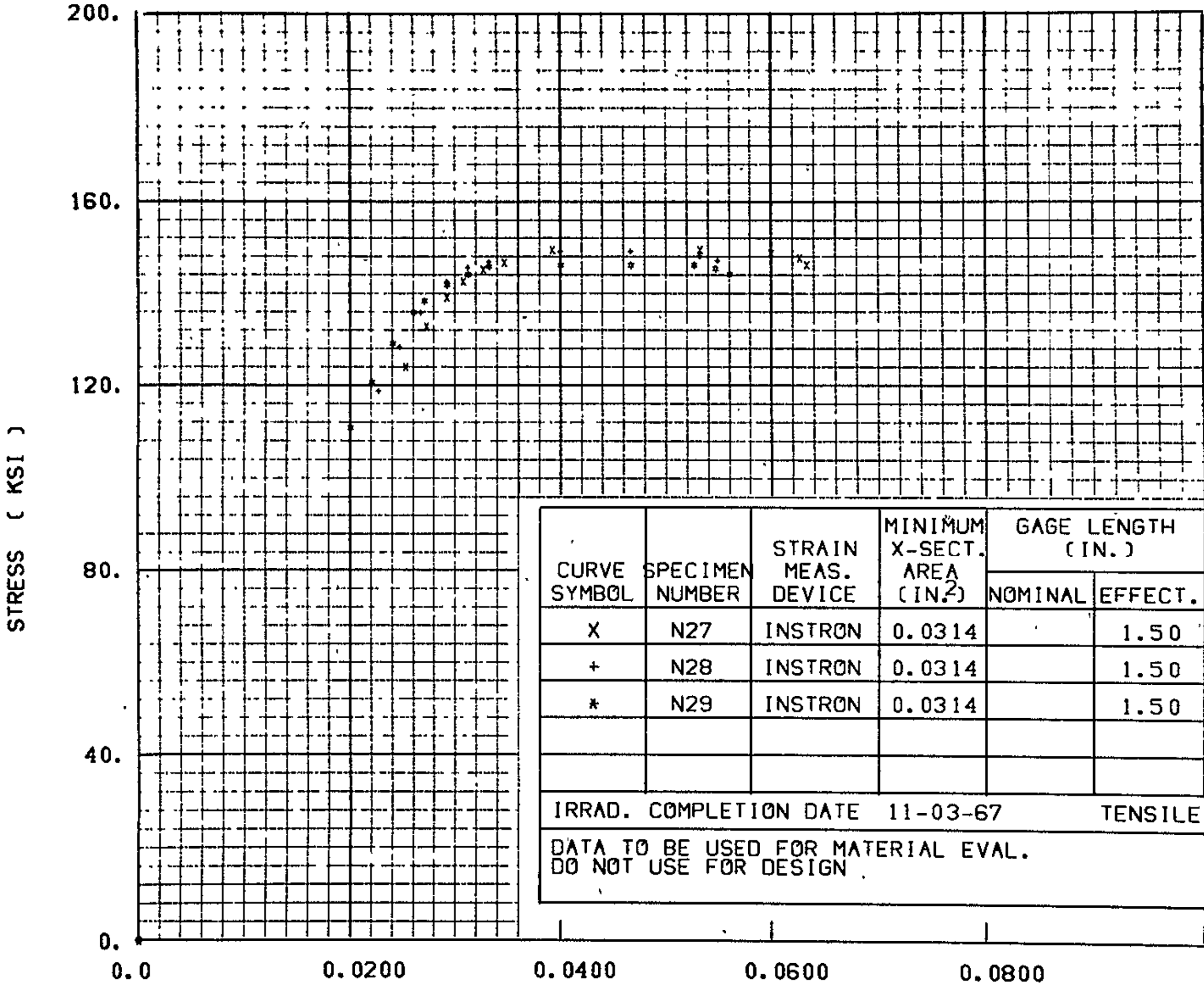
CURVE SYMBOL	SPECIMEN NUMBER	STRAIN MEAS. DEVICE	MINIMUM X-SECT. AREA (IN.^{2})	GAGE LENGTH (IN.) NOMINAL	GAGE LENGTH (IN.) EFFECT.	FLUENCE (NEUTRONS/CM^2) THERMAL	FLUENCE (NEUTRONS/CM^2) FAST	GAMMA DOSE (ERGS/GM(C))
X	N24	INSTRON	0.0314		1.50	CONT		
+	N25	INSTRON	0.0315		1.50	CONT		
*	N26	INSTRON	0.0315		1.50	CONT		

IRRAD. COMPLETION DATE 11-03-67 TENSILE TEST DATE MAR. 68

DATA TO BE USED FOR MATERIAL EVAL.
DO NOT USE FOR DESIGN

FIGURE 6-64 STRESS-STRAIN CURVES FOR INCONEL 718(37 PPM B).
CONTROLS. 1660 R (0.0013 IN./IN./MIN). FITTED TO HDBK MOD

NPC 26,895



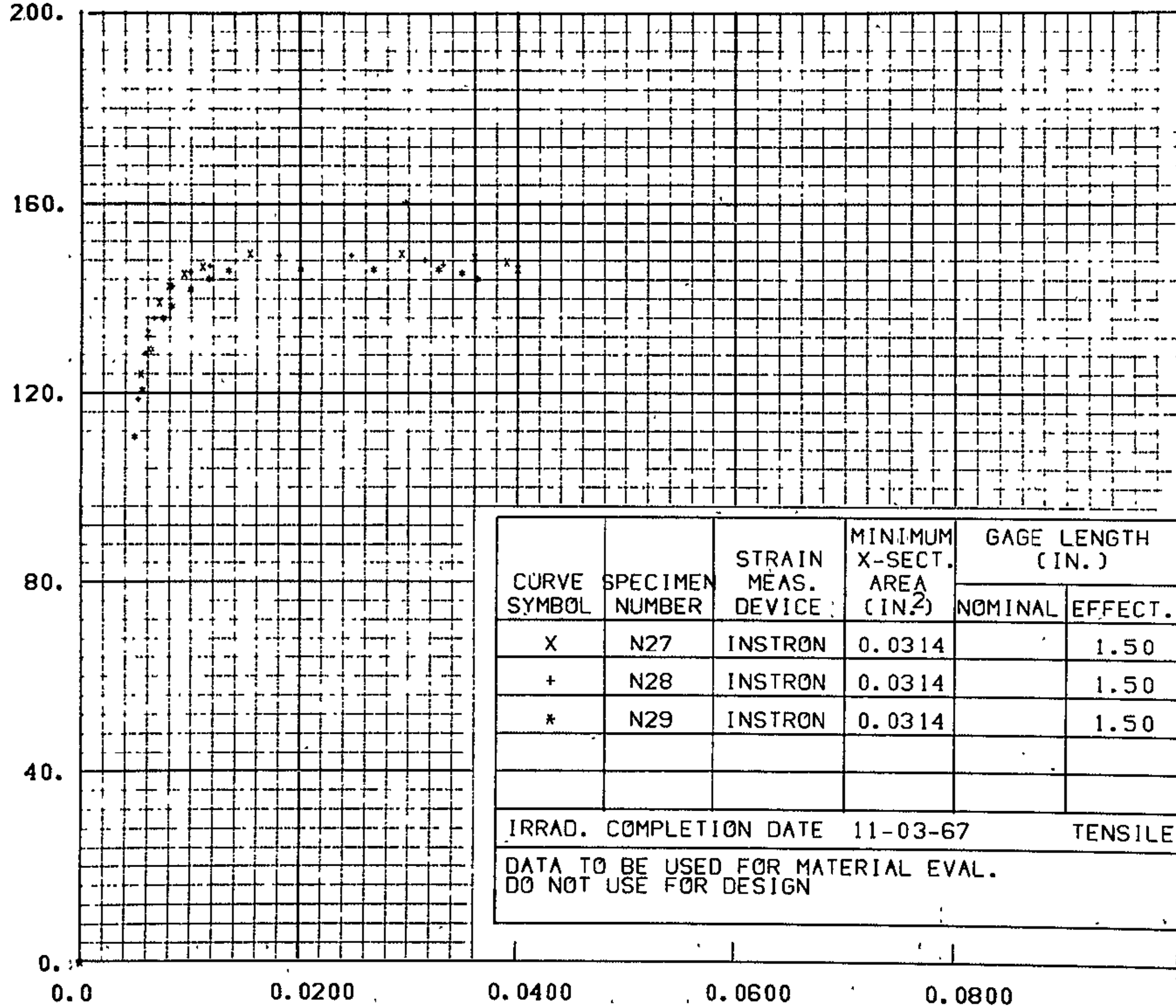
CURVE SYMBOL	SPECIMEN NUMBER	STRAIN MEAS. DEVICE	MINIMUM X-SECT. AREA (IN.^{2})	GAGE LENGTH (IN.) NOMINAL	GAGE LENGTH (IN.) EFFECT.	FLUENCE (NEUTRONS/CM^2) THERMAL	FLUENCE (NEUTRONS/CM^2) FAST	GAMMA DOSE (ERGS/GM(C))
X	N27	INSTRON	0.0314		1.50	7.7+15	4.4+15	2.0+11
+	N28	INSTRON	0.0314		1.50	8.0+15	4.5+15	2.1+11
*	N29	INSTRON	0.0314		1.50	8.3+15	4.7+15	2.2+11

IRRAD. COMPLETION DATE 11-03-67 TENSILE TEST DATE MAR. 68

DATA TO BE USED FOR MATERIAL EVAL.
DO NOT USE FOR DESIGN

FIGURE 6-65 STRESS-STRAIN CURVES FOR INCONEL 718(37 PPM B).
LOW IRRAD. TESTED AT 1660 R (0.0013 IN./IN./MIN)

NPC 26,896



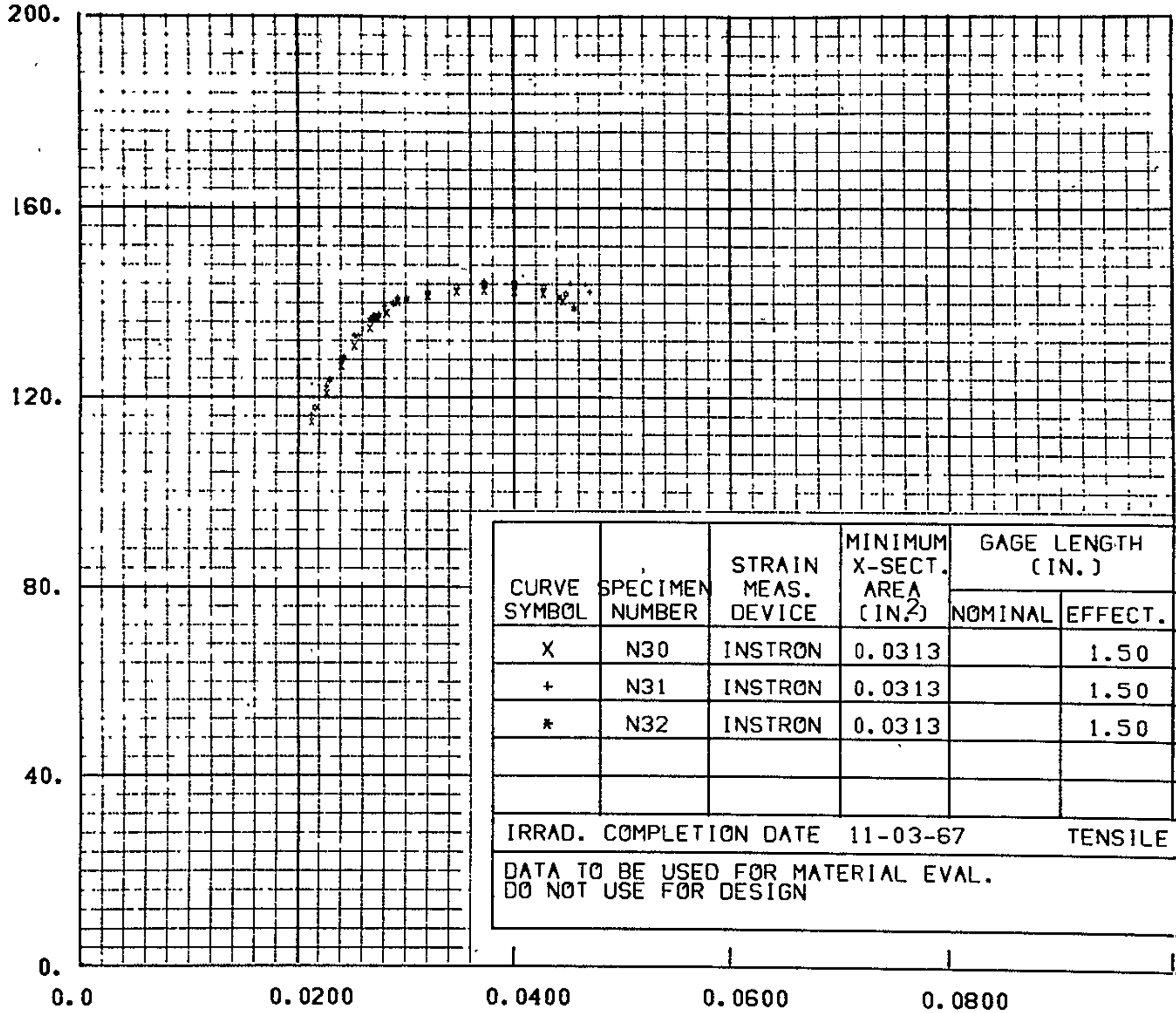
CURVE SYMBOL	SPECIMEN NUMBER	STRAIN MEAS. DEVICE	MINIMUM X-SECT. AREA (IN.^{2})	GAGE LENGTH (IN.)		FLUENCE (NEUTRONS/CM^2)		GAMMA DOSE (ERGS/GM(C))
				NOMINAL	EFFECT.	THERMAL	FAST	
X	N27	INSTRON	0.0314		1.50	7.7+15	4.4+15	2.0+11
+	N28	INSTRON	0.0314		1.50	8.0+15	4.5+15	2.1+11
*	N29	INSTRON	0.0314		1.50	8.3+15	4.7+15	2.2+11

IRRAD. COMPLETION DATE 11-03-67 TENSILE TEST DATE MAR. 68

DATA TO BE USED FOR MATERIAL EVAL.
DO NOT USE FOR DESIGN

STRAIN (IN./IN. OF GAGE LENGTH)(BASED ON HANDBOOK MODULUS)

FIGURE 6-66 STRESS-STRAIN CURVES FOR INCONEL 718(37 PPM B).
LOW IRRAD. 1660 R.(0.0013 IN./IN./MIN). FITTED TO HDBK MOD



CURVE SYMBOL	SPECIMEN NUMBER	STRAIN MEAS. DEVICE	MINIMUM X-SECT. AREA (IN.^{2})	GAGE LENGTH (IN.)		FLUENCE (NEUTRONS/CM^2)		GAMMA DOSE (ERGS/GM(C))
				NOMINAL	EFFECT.	THERMAL	FAST	
X	N30	INSTRON	0.0313		1.50	1.7+17	7.0+16	7.8+11
+	N31	INSTRON	0.0313		1.50	1.8+17	7.4+16	8.1+11
*	N32	INSTRON	0.0313		1.50	1.9+17	7.8+16	8.4+11

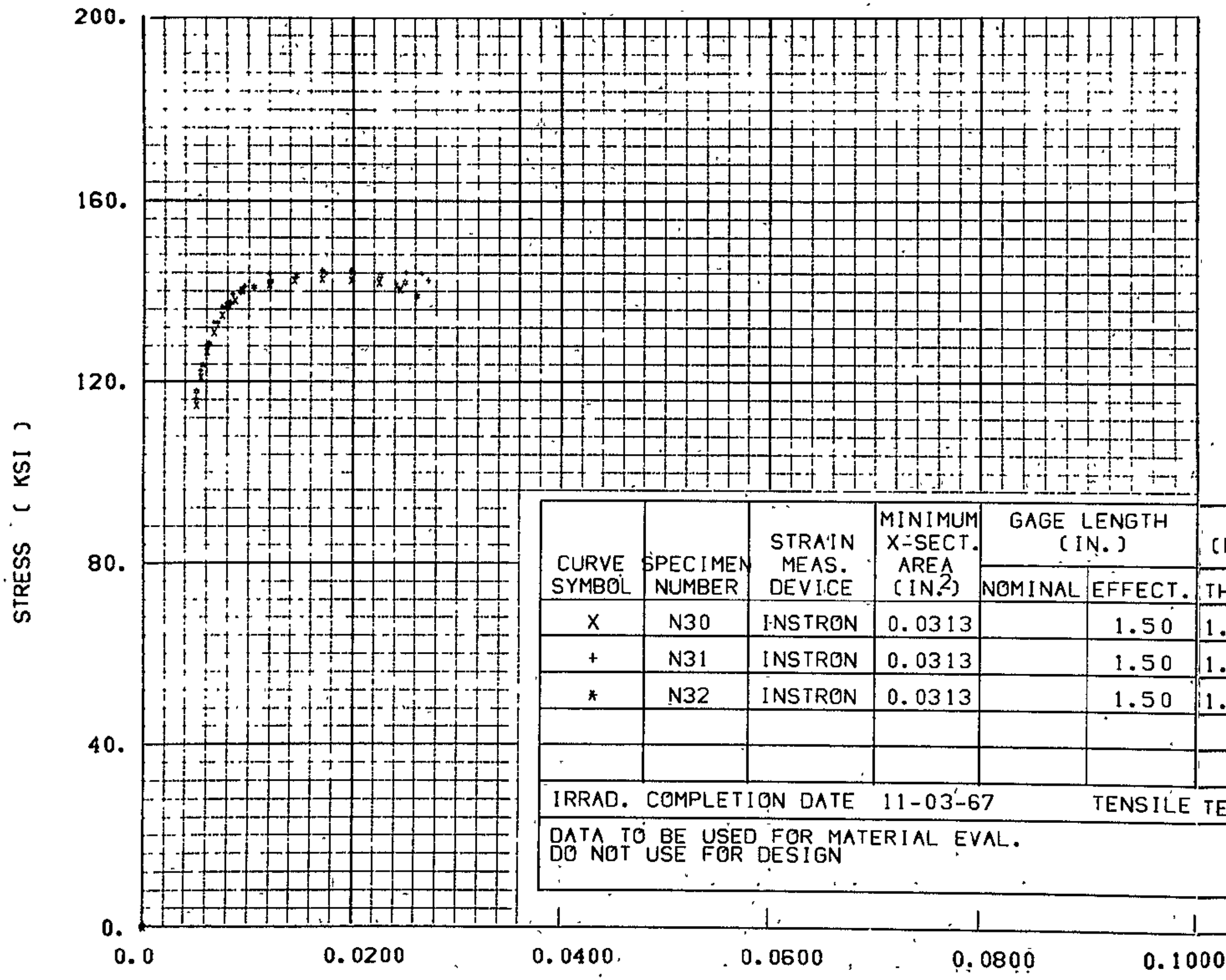
IRRAD. COMPLETION DATE 11-03-67 TENSILE TEST DATE MAR. 68

DATA TO BE USED FOR MATERIAL EVAL.
DO NOT USE FOR DESIGN

STRAIN (IN./IN. OF GAGE LENGTH)(BASED ON CROSSHEAD TRAVEL)

FIGURE 6-67 STRESS-STRAIN CURVES FOR INCONEL 718(37 PPM B).
MED IRRAD. TESTED AT 1660 R (0.0013 IN./IN./MIN)

NPC 26,898



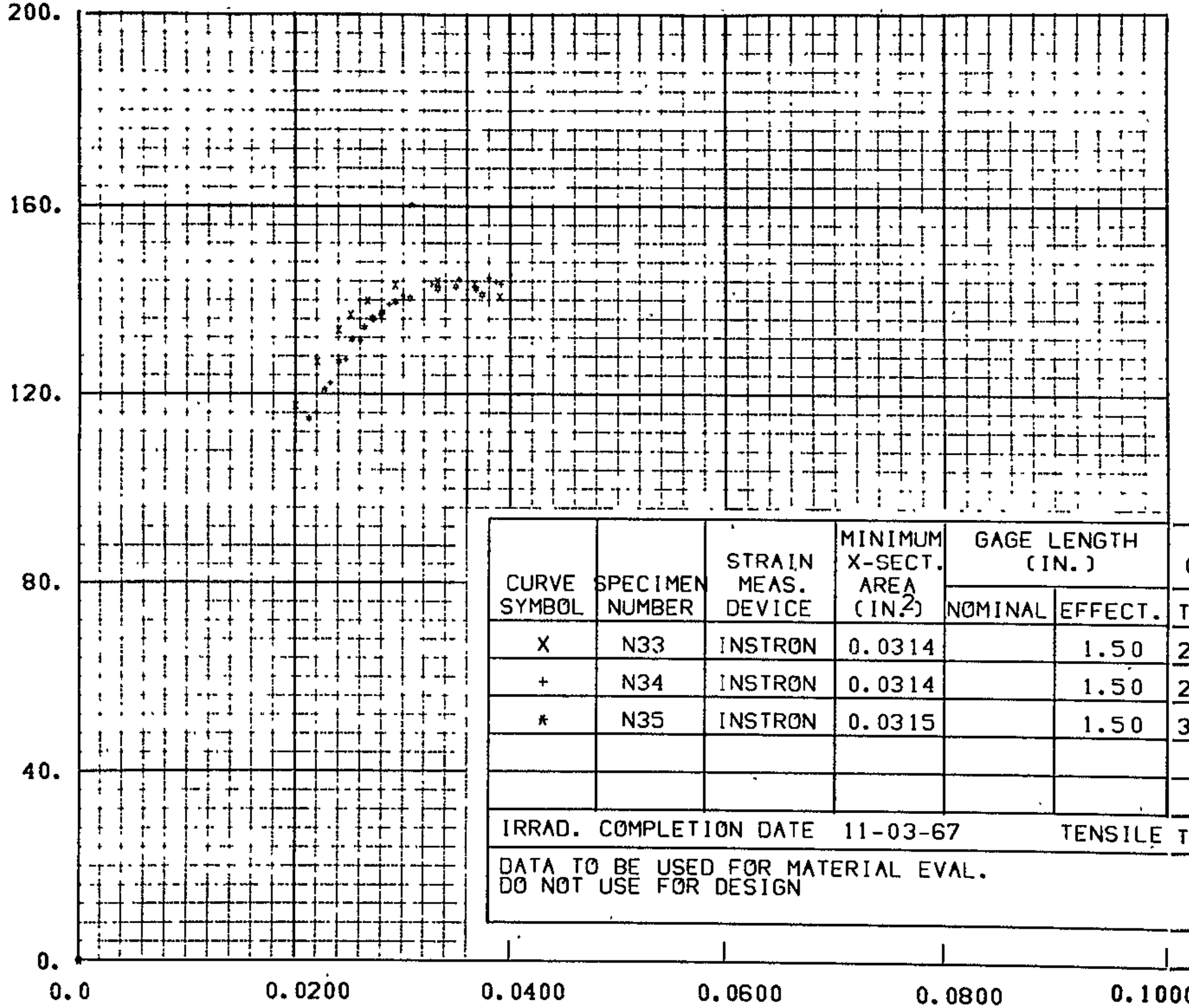
CURVE SYMBOL	SPECIMEN NUMBER	STRAIN MEAS. DEVICE	MINIMUM X-SECT. AREA (IN.^{2})	GAGE LENGTH (IN.)		FLUENCE (NEUTRONS/CM^2)		GAMMA DOSE (ERGS/GM(C))
				NOMINAL	EFFECT.	THERMAL	FAST	
X	N30	INSTRON	0.0313		1.50	1.7+17	7.0+16	7.8+11
+	N31	INSTRON	0.0313		1.50	1.8+17	7.4+16	8.1+11
*	N32	INSTRON	0.0313		1.50	1.9+17	7.8+16	8.4+11

IRRAD. COMPLETION DATE 11-03-67 TENSILE TEST DATE MAR. 68

DATA TO BE USED FOR MATERIAL EVAL.
DO NOT USE FOR DESIGN

FIGURE 6-68 STRESS-STRAIN CURVES FOR INCONEL 718(37 PPM B).
MED IRRAD. 1660 R (0.0013 IN./IN./MIN), FITTED TO HDBK MOD

NPC 26,899



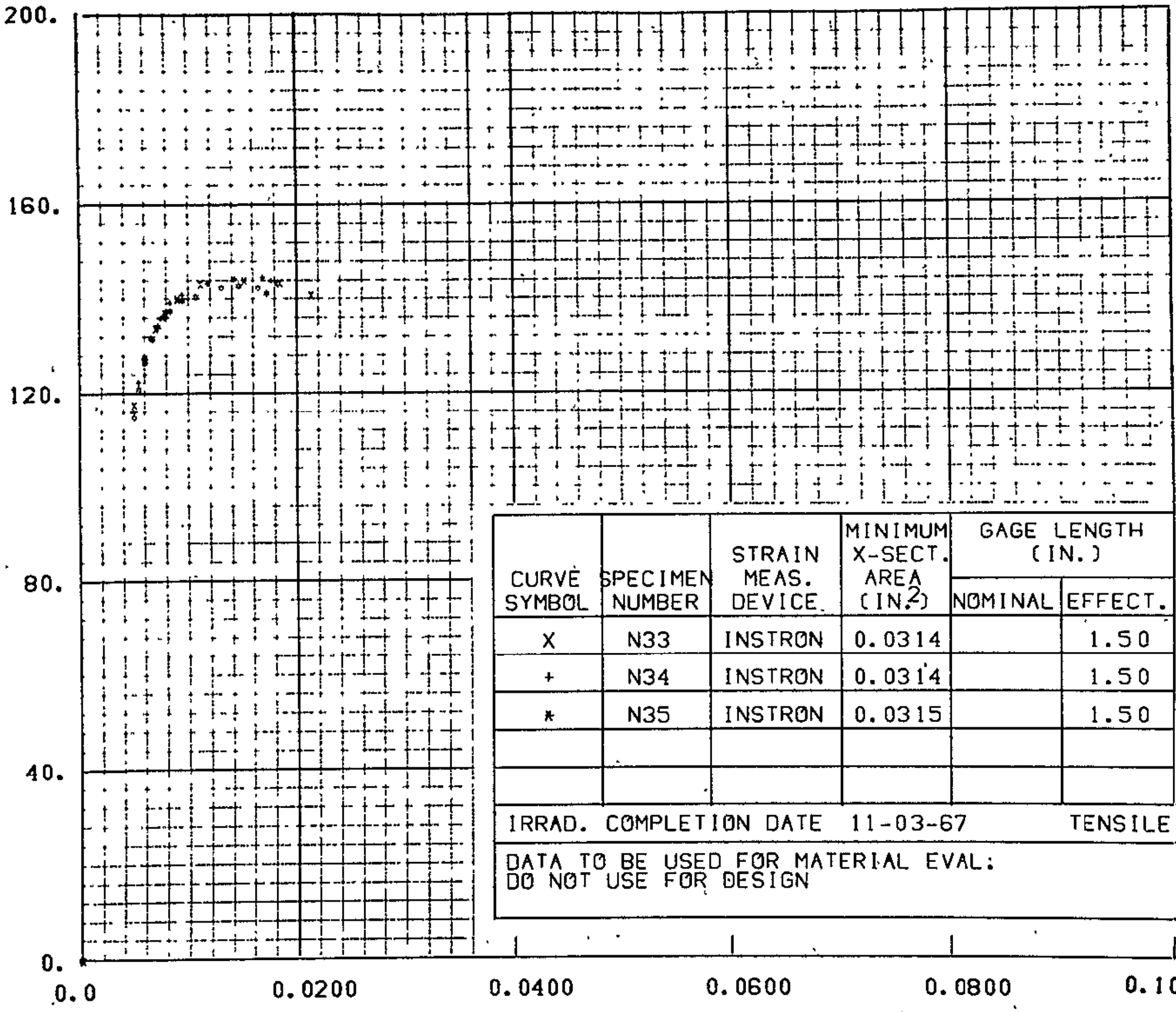
CURVE SYMBOL	SPECIMEN NUMBER	STRAIN MEAS. DEVICE	MINIMUM X-SECT. AREA (IN.^{2})	GAGE LENGTH (IN.)		FLUENCE (NEUTRONS/CM^2)		GAMMA DOSE (ERGS/ GM(C))
				NOMINAL	EFFECT.	THERMAL	FAST	
X	N33	INSTRON	0.0314		1.50	2.2+18	6.2+17	2.3+12
+	N34	INSTRON	0.0314		1.50	2.1+18	6.0+17	2.3+12
*	N35	INSTRON	0.0315		1.50	3.2+18	7.6+17	2.5+12

IRRAD. COMPLETION DATE 11-03-67 TENSILE TEST DATE MAR. 68

DATA TO BE USED FOR MATERIAL EVAL.
DO NOT USE FOR DESIGN

STRAIN (IN./IN. OF GAGE LENGTH)(BASED ON CROSSHEAD TRAVEL)

FIGURE 6-69 STRESS-STRAIN CURVES FOR INCONEL 718(37 PPM B).
HIGH IRRAD. TESTED AT 1660 R (0.0013 IN./IN./MIN)



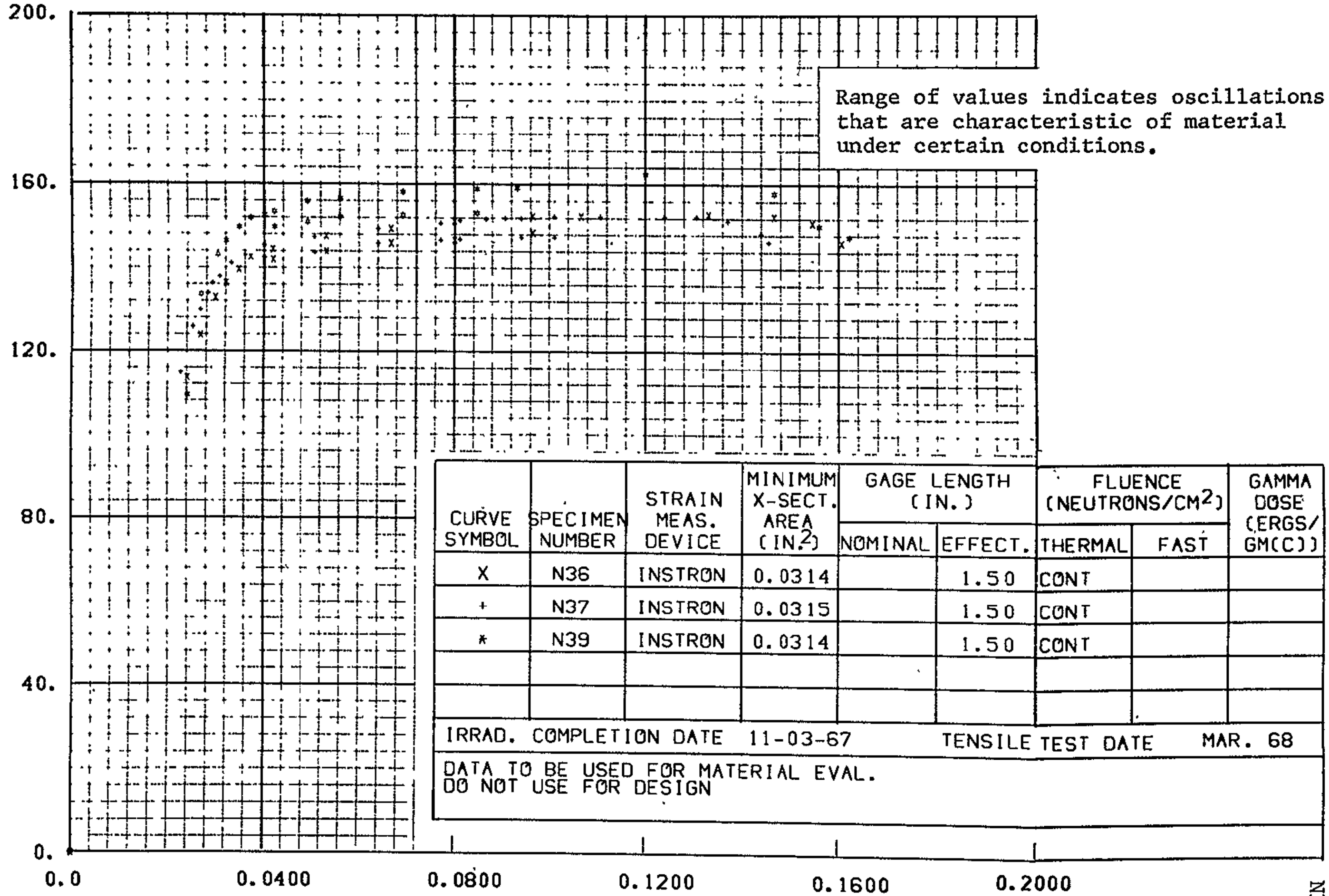
CURVE SYMBOL	SPECIMEN NUMBER	STRAIN MEAS. DEVICE	MINIMUM X-SECT. AREA (IN.^{2})	GAGE LENGTH (IN.)		FLUENCE (NEUTRONS/CM^2)		GAMMA DOSE (ERGS/GM(C))
				NOMINAL	EFFECT.	THERMAL	FAST	
X	N33	INSTRON	0.0314		1.50	2.2+18	6.2+17	2.3+12
+	N34	INSTRON	0.0314		1.50	2.1+18	6.0+17	2.3+12
*	N35	INSTRON	0.0315		1.50	3.2+18	7.6+17	2.5+12

IRRAD. COMPLETION DATE 11-03-67 TENSILE TEST DATE MAR. 68

DATA TO BE USED FOR MATERIAL EVAL:
DO NOT USE FOR DESIGN

STRAIN (IN./IN. OF GAGE LENGTH)(BASED ON HANDBOOK MODULUS)

FIGURE 6-70 STRESS-STRAIN CURVES FOR INCONEL 718(37 PPM B).
HIGH IRRAD. 1660 R (0.0013 IN./IN./MIN). FITTED TO HDBK MOD



CURVE SYMBOL	SPECIMEN NUMBER	STRAIN MEAS. DEVICE	MINIMUM X-SECT. AREA (IN.^{2})	GAGE LENGTH (IN.) NOMINAL	GAGE LENGTH (IN.) EFFECT.	FLUENCE (NEUTRONS/CM^2) THERMAL	FLUENCE (NEUTRONS/CM^2) FAST	GAMMA DOSE (ERGS/GM(C))
X	N36	INSTRON	0.0314		1.50	CONT		
+	N37	INSTRON	0.0315		1.50	CONT		
*	N39	INSTRON	0.0314		1.50	CONT		

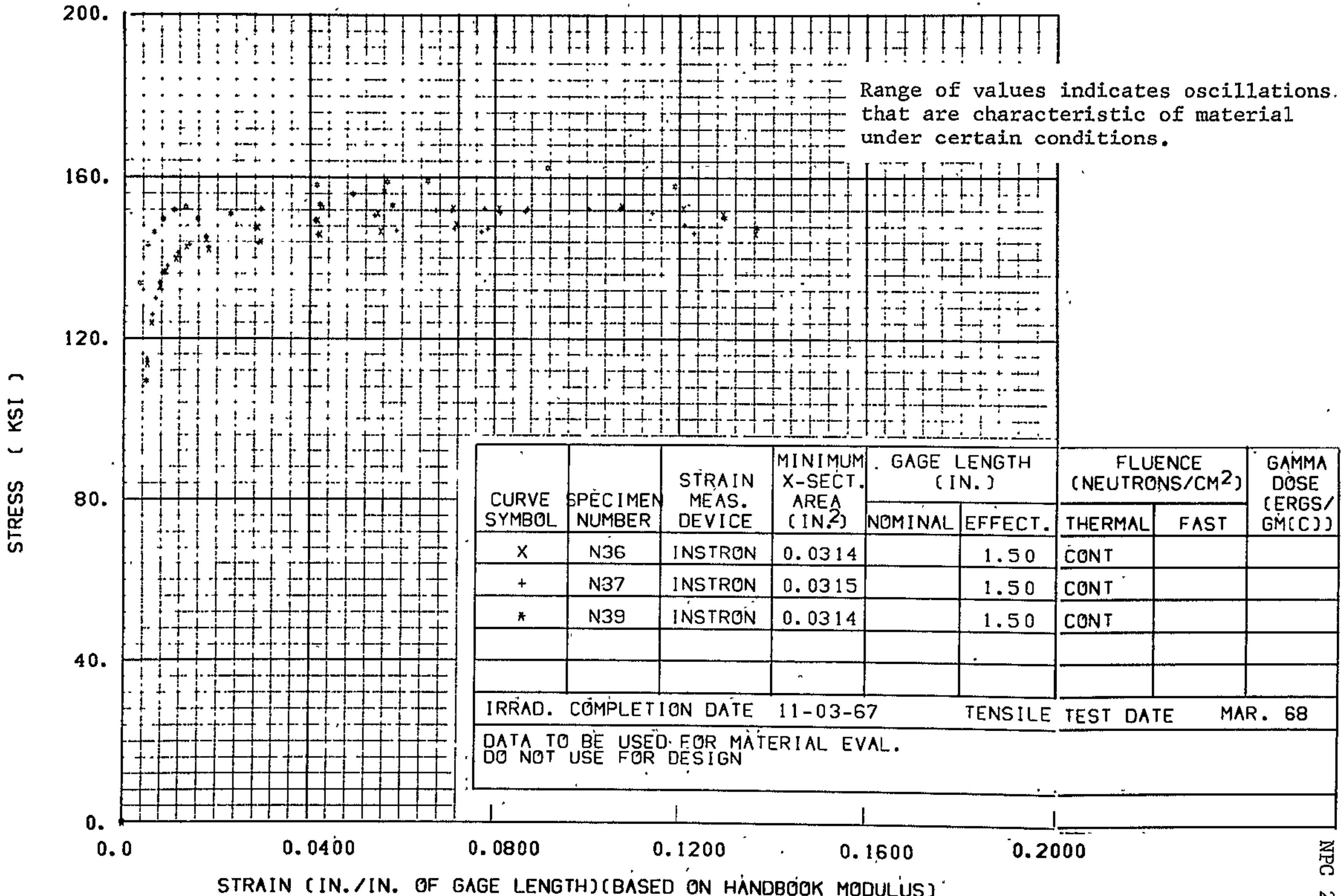
IRRAD. COMPLETION DATE 11-03-67 TENSILE TEST DATE MAR. 68

DATA TO BE USED FOR MATERIAL EVAL.
DO NOT USE FOR DESIGN

STRAIN (IN./IN. OF GAGE LENGTH)(BASED ON CROSSHEAD TRAVEL)

FIGURE 6-71 STRESS-STRAIN CURVES FOR INCONEL 718(37 PPM B). CONTROLS. TESTED AT 1660 R (0.13 IN./IN./MIN)

NPC 26,902



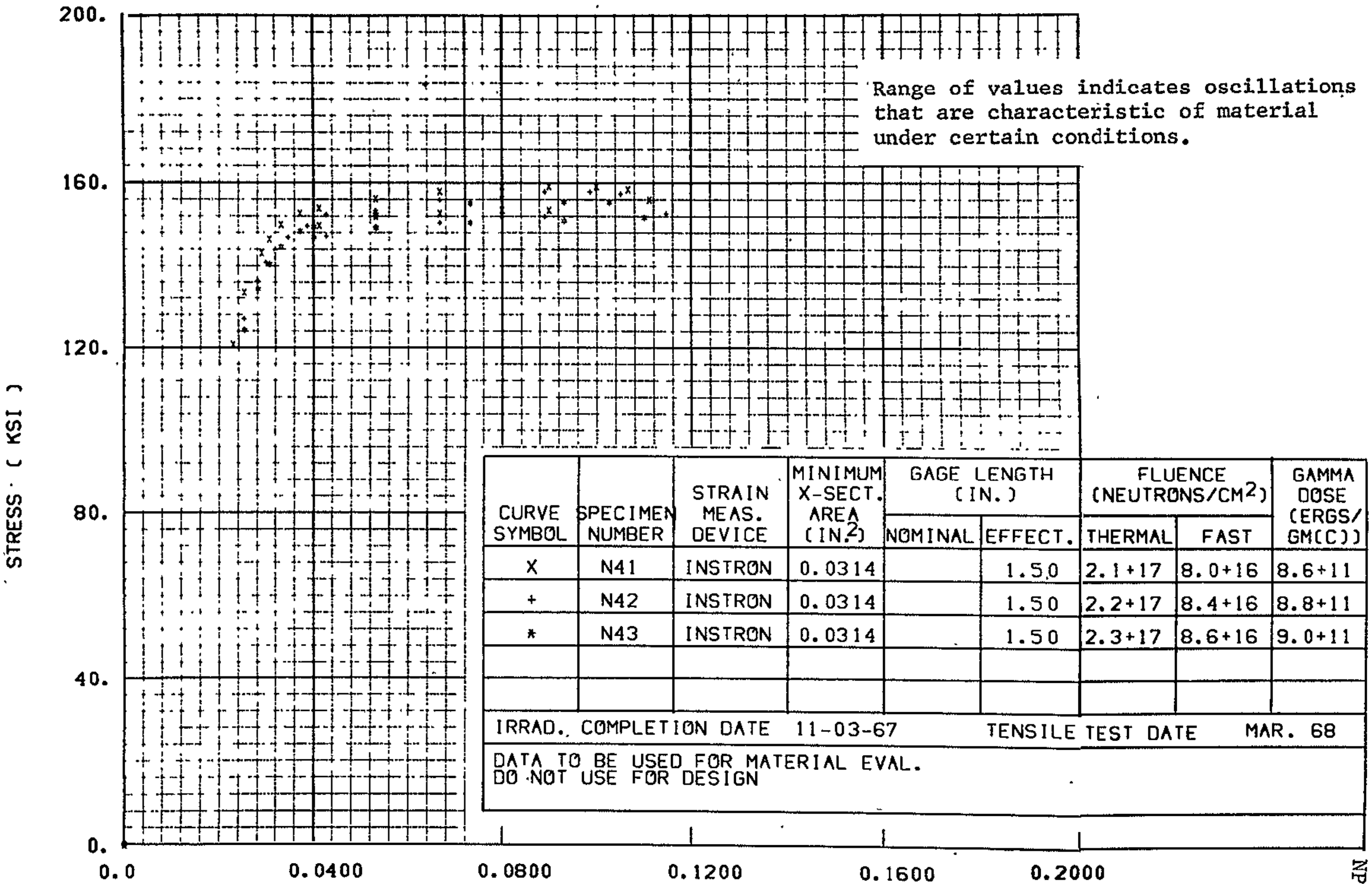
CURVE SYMBOL	SPECIMEN NUMBER	STRAIN MEAS. DEVICE	MINIMUM X-SECT. AREA (IN.^{2})	GAGE LENGTH (IN.) NOMINAL	GAGE LENGTH (IN.) EFFECT.	FLUENCE (NEUTRONS/CM^2) THERMAL	FLUENCE (NEUTRONS/CM^2) FAST	GAMMA DOSE (ERGS/GM(C))
X	N36	INSTRON	0.0314		1.50	CONT		
+	N37	INSTRON	0.0315		1.50	CONT		
*	N39	INSTRON	0.0314		1.50	CONT		

IRRAD. COMPLETION DATE 11-03-67 TENSILE TEST DATE MAR. 68

DATA TO BE USED FOR MATERIAL EVAL.
DO NOT USE FOR DESIGN

FIGURE 6-72 STRESS-STRAIN CURVES FOR INCONEL 718(37 PPM B), CONTROLS, 1660 R (0.13 IN./IN./MIN), FITTED TO HDBK MOD

NPC 26,903



CURVE SYMBOL	SPECIMEN NUMBER	STRAIN MEAS. DEVICE	MINIMUM X-SECT. AREA (IN.^{2})	GAGE LENGTH (IN.) NOMINAL	GAGE LENGTH (IN.) EFFECT.	FLUENCE (NEUTRONS/CM^2) THERMAL	FLUENCE (NEUTRONS/CM^2) FAST	GAMMA DOSE (ERGS/GM(C))
X	N41	INSTRON	0.0314		1.50	2.1+17	8.0+16	8.6+11
+	N42	INSTRON	0.0314		1.50	2.2+17	8.4+16	8.8+11
*	N43	INSTRON	0.0314		1.50	2.3+17	8.6+16	9.0+11

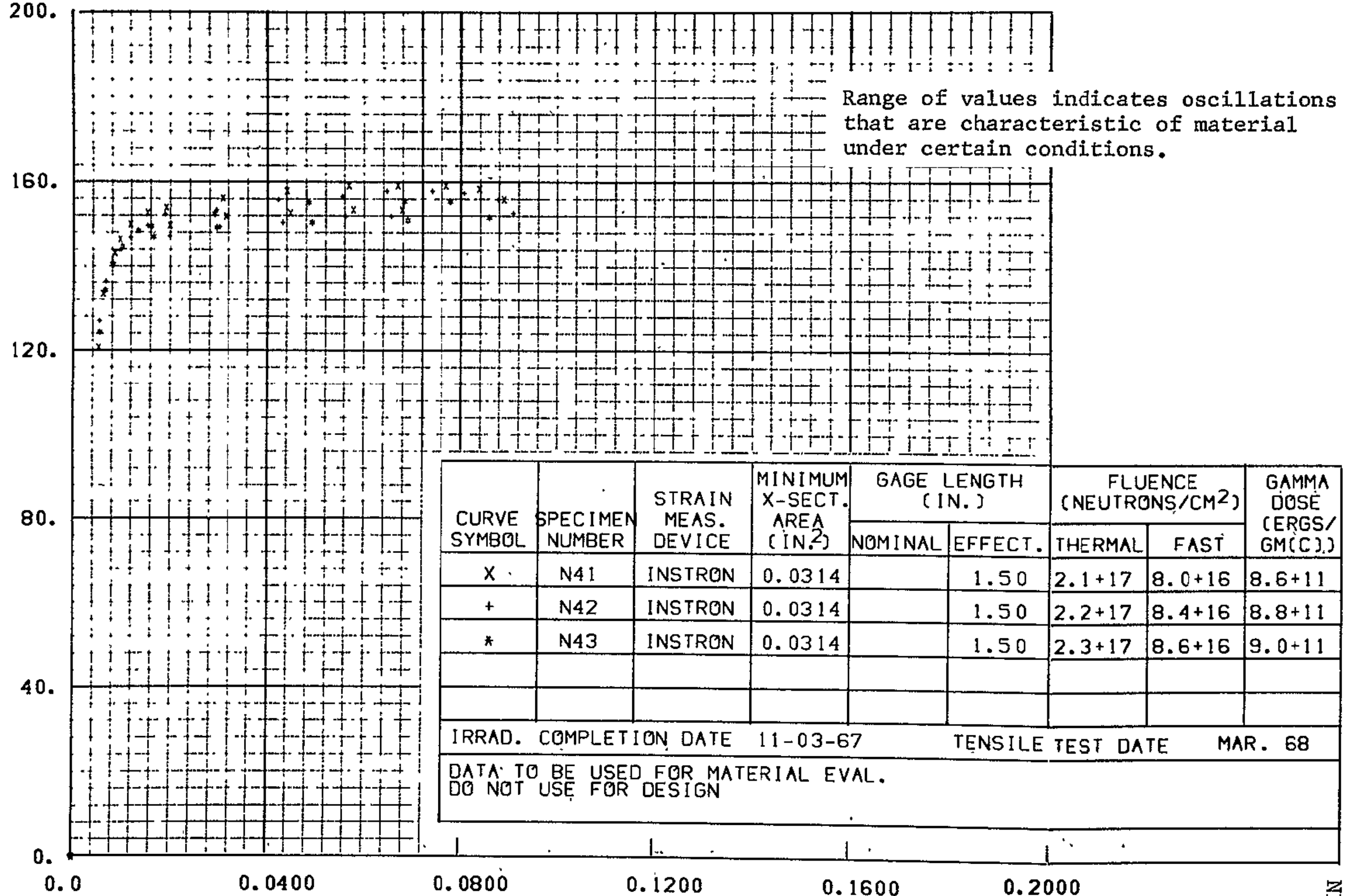
IRRAD. COMPLETION DATE 11-03-67 TENSILE TEST DATE MAR. 68

DATA TO BE USED FOR MATERIAL EVAL.
DO NOT USE FOR DESIGN

STRAIN (IN./IN. OF GAGE LENGTH)(BASED ON CROSSHEAD TRAVEL)

FIGURE 6-73 STRESS-STRAIN CURVES FOR INCONEL 718(37 PPM B). MED IRRAD. TESTED AT 1660 R (0.13 IN./IN./MIN)

NPC 26,904



CURVE SYMBOL	SPECIMEN NUMBER	STRAIN MEAS. DEVICE	MINIMUM X-SECT. AREA ($IN.^2$)	GAGE LENGTH (IN.) NOMINAL	GAGE LENGTH (IN.) EFFECT.	FLUENCE (NEUTRONS/CM^2) THERMAL	FLUENCE (NEUTRONS/CM^2) FAST	GAMMA DOSE (ERGS/ GM(C))
X	N41	INSTRON	0.0314		1.50	2.1+17	8.0+16	8.6+11
+	N42	INSTRON	0.0314		1.50	2.2+17	8.4+16	8.8+11
*	N43	INSTRON	0.0314		1.50	2.3+17	8.6+16	9.0+11

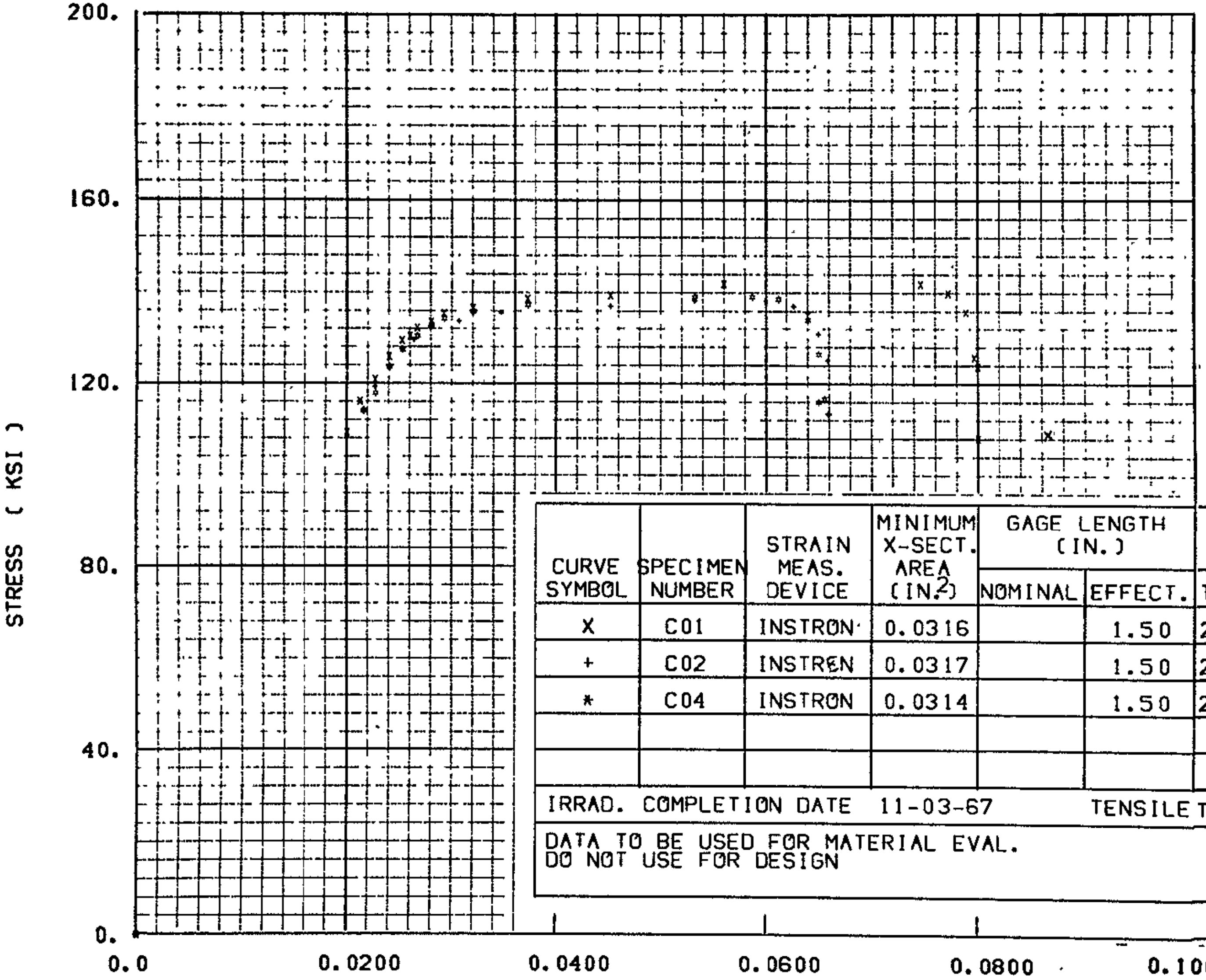
IRRAD. COMPLETION DATE 11-03-67 TENSILE TEST DATE MAR. 68

DATA TO BE USED FOR MATERIAL EVAL.
DO NOT USE FOR DESIGN

STRAIN (IN./IN. OF GAGE LENGTH)(BASED ON HANDBOOK MODULUS)

FIGURE 6-74 STRESS-STRAIN CURVES FOR INCONEL 718(37 PPM B).
MED IRRAD. 1660 R (0.13 IN./IN./MIN). FITTED TO HDBK MOD

NPC 26,905



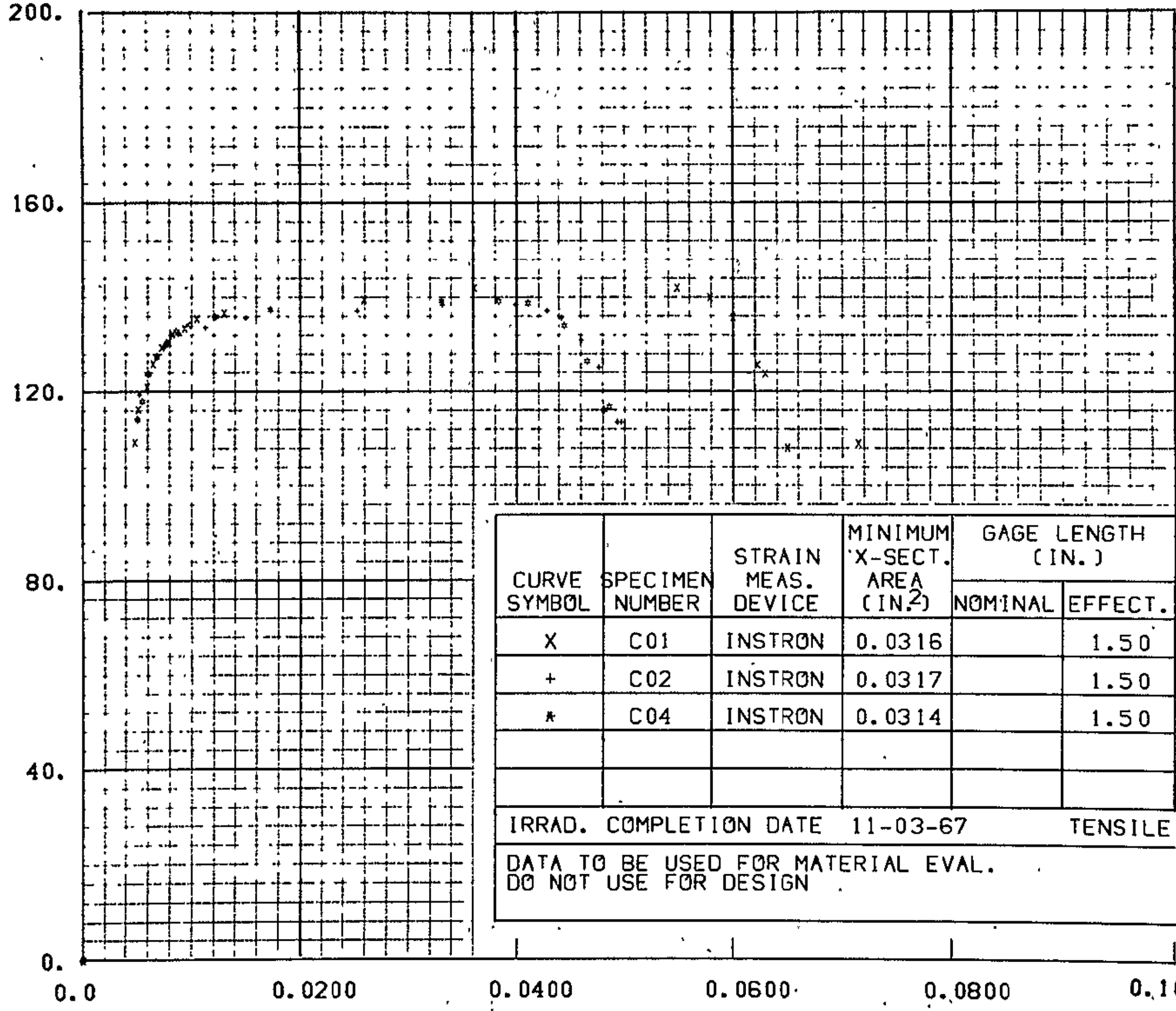
CURVE SYMBOL	SPECIMEN NUMBER	STRAIN MEAS. DEVICE	MINIMUM X-SECT. AREA ($IN.^2$)	GAGE LENGTH (IN.) NOMINAL	GAGE LENGTH (IN.) EFFECT.	FLUENCE ($NEUTRONS/CM^2$) THERMAL	FLUENCE ($NEUTRONS/CM^2$) FAST	GAMMA DOSE (ERGS/GM(C))
X	C01	INSTRON	0.0316		1.50	2.4+17	9.0+16	9.4+11
+	C02	INSTRON	0.0317		1.50	2.3+17	8.8+16	9.3+11
*	C04	INSTRON	0.0314		1.50	2.2+17	8.4+16	9.2+11

IRRAD. COMPLETION DATE 11-03-67 TENSILE TEST DATE MAR. 68

DATA TO BE USED FOR MATERIAL EVAL.
DO NOT USE FOR DESIGN

FIGURE 6-75 STRESS-STRAIN CURVES FOR INCONEL 718(46 PPM B).
MED IRRAD. TESTED AT 1660 R (0.0013 IN./IN./MIN)

NPC 26,906



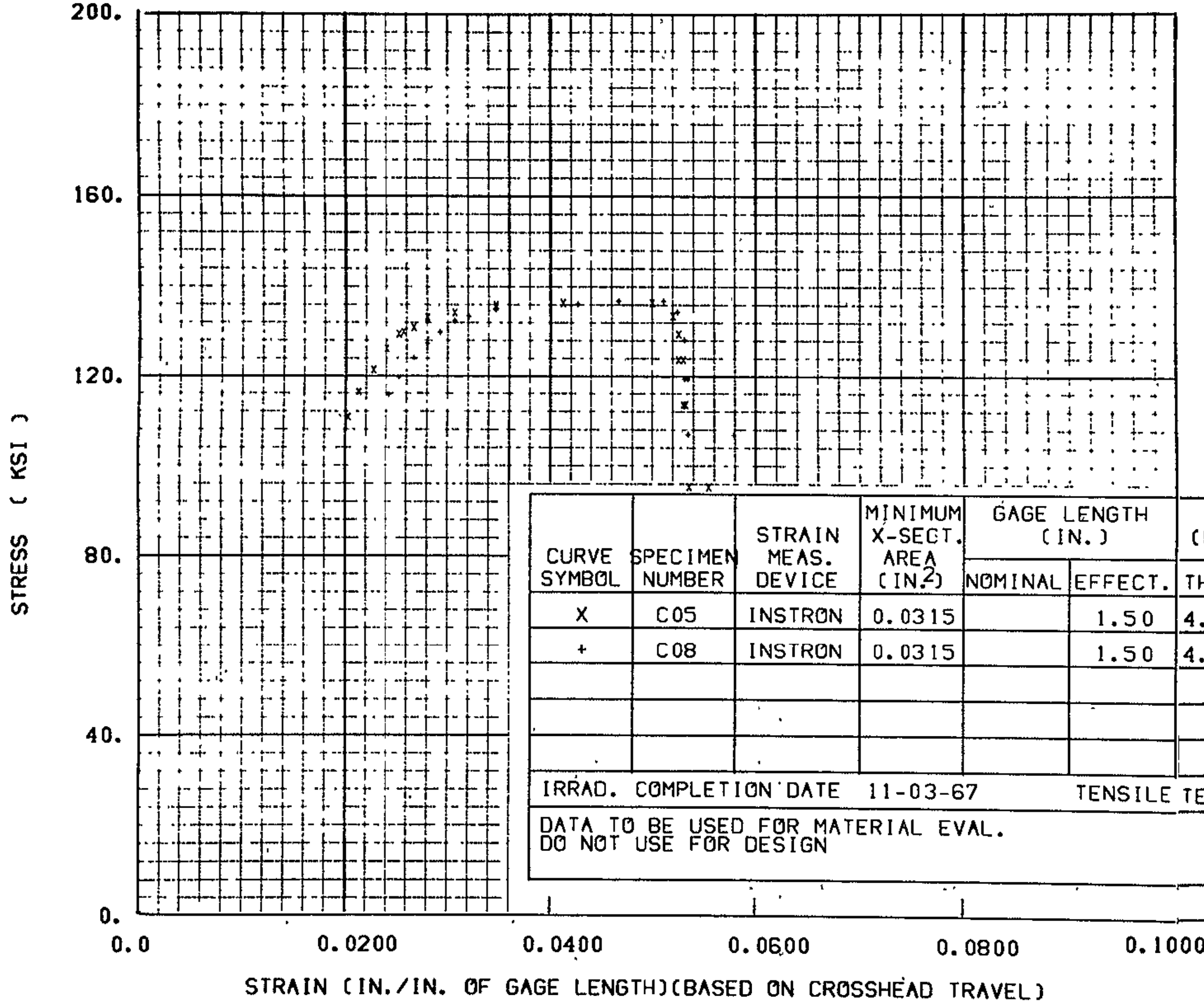
CURVE SYMBOL	SPECIMEN NUMBER	STRAIN MEAS. DEVICE	MINIMUM X-SECT. AREA (IN.2)	GAGE LENGTH (IN.) NOMINAL	GAGE LENGTH (IN.) EFFECT.	FLUENCE (NEUTRONS/CM2) THERMAL	FLUENCE (NEUTRONS/CM2) FAST	GAMMA DOSE (ERGS/GM(C))
X	C01	INSTRON	0.0316		1.50	2.4+17	9.0+16	9.4+11
+	C02	INSTRON	0.0317		1.50	2.3+17	8.8+16	9.3+11
*	C04	INSTRON	0.0314		1.50	2.2+17	8.4+16	9.2+11

IRRAD. COMPLETION DATE 11-03-67 TENSILE TEST DATE MAR. 68

DATA TO BE USED FOR MATERIAL EVAL.
DO NOT USE FOR DESIGN .

FIGURE 6-76 STRESS-STRAIN CURVES FOR INCONEL 718(46 PPM B).
MED IRRAD. 1660 R (0.0013 IN./IN./MIN). FITTED TO HDBK MOD

NPC 26,907



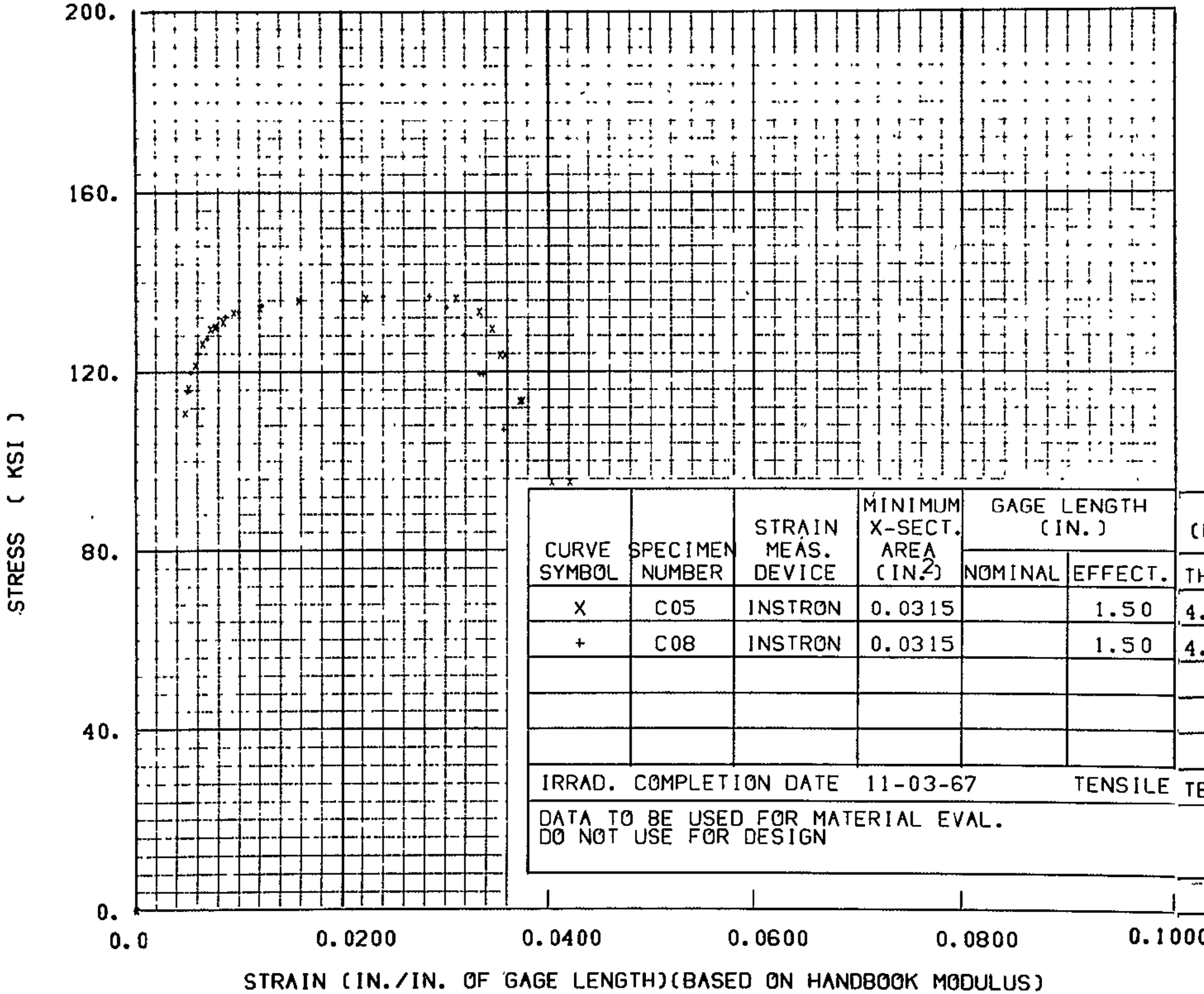
CURVE SYMBOL	SPECIMEN NUMBER	STRAIN MEAS. DEVICE	MINIMUM X-SECT. AREA (IN.^{2})	GAGE LENGTH (IN.)		FLUENCE (NEUTRONS/CM^2)		GAMMA DOSE (ERGS/GM(C))
				NOMINAL	EFFECT.	THERMAL	FAST	
X	C05	INSTRON	0.0315		1.50	4.1+18	9.7+17	2.8+12
+	C08	INSTRON	0.0315		1.50	4.3+18	1.0+18	2.9+12

IRRAD. COMPLETION DATE 11-03-67 TENSILE TEST DATE MAR. 68

DATA TO BE USED FOR MATERIAL EVAL.
DO NOT USE FOR DESIGN

FIGURE 6-77 STRESS-STRAIN CURVES FOR INCONEL 718(46 PPM B).
HIGH IRRAD, TESTED AT 1660 R (0.0013 IN./IN./MIN)

NPC 26,908



CURVE SYMBOL	SPECIMEN NUMBER	STRAIN MEAS. DEVICE	MINIMUM X-SECT. AREA (IN.^{2})	GAGE LENGTH (IN.) NOMINAL	GAGE LENGTH (IN.) EFFECT.	FLUENCE (NEUTRONS/CM^2) THERMAL	FLUENCE (NEUTRONS/CM^2) FAST	GAMMA DOSE (ERGS/GM(C))
X	C05	INSTRON	0.0315		1.50	4.1+18	9.7+17	2.8+12
+	C08	INSTRON	0.0315		1.50	4.3+18	1.0+18	2.9+12

IRRAD. COMPLETION DATE 11-03-67 TENSILE TEST DATE MAR. 68

DATA TO BE USED FOR MATERIAL EVAL.
DO NOT USE FOR DESIGN

FIGURE 6-78 STRESS-STRAIN CURVES FOR INCONEL 718(46 PPM B).
HIGH IRRAD, 1660 R (0.0013 IN./IN./MIN), FITTED TO HDBK MOD

NPC 26,809

Section 6.5

Presentation of Waspaloy Stress-Rupture Data

PRECEDING PAGE BLANK NOT FILMED

INDEX TO WASPALOY STRESS-RUPTURE DATA

Configuration and Condition	Test Temp (^oR)	Stress (ksi)	Spec. No.	Stress-Rupture Data Table	Stress-Rupture Data Page	Stress-Rupture Curves Fig.	Stress-Rupture Curves Page	Effect of Radiation Fig.	Effect of Radiation Page
Round-Unnotched									
Control	1660	115	W 47	6-12	6-130	-	-	-	-
		105	W 48			6-79	6-132	6-86	6-139
		105-135	W 50						
		105-125	W 72						
Low Irrad	1660	105	W 53			6-80	6-133		
		105	W 54						
		105	W 56						
Medium Irrad	1660	105	W 57			6-81	6-134		
		105	W 58						
		105	W 60						
High Irrad	1660	105	W 61			6-82	6-135		
		105	W 62						
		105	W 63						
Combination-Notched									
Control	1860	70-80	WS 01		6-131	6-83	6-136	6-87	6-140
		70-80	WS 02						
Low Irrad	1860	70	WS 03			6-84	6-137		
		70	WS 04						
Medium Irrad	1860	70	WS 05			6-85	6-138		
		70	WS 06						

PRECEDING PAGE BLANK NOT FILMED

Table 6-12

STRESS-RUPTURE TEST DATA FOR INDIVIDUAL SPECIMENS OF WASPALOY

Specimen Configuration: round-unnotched (W) - AGC Dwg. 1134298-1
combination-notched (WS) - AGC Dwg. 1134453 Data to be used for material evaluation only. Do not use for design.

Specimen Number	Condition	Test Temp (°R)	Stress (ksi)	Time to Failure (h)	% Elongation		% Area Reduct (Bench)	Frac Loca-tion	Date Failed	Radiation Exposure		
										Gamma Dose	Neutron Fluence (n/cm^2)	
					Bench	Chart				[ergs/g(C)]	E > 1.0 MeV	E < 0.48 eV
W 47[a]	Control	1660	115	14.5	22.1	-	31.0	2	3/22/68			
W 48			105	61.1	18.5	16.8	25.7	2	3/29/68			
W 50			105-135	105.6	13.7	13.4	18.2	2	4/16/68			
W 72			105-125	103.7	14.4	14.3	20.6	1	5/21/68			
Average				90.1	15.5	14.8	21.5					
Std Dev				25.2	2.6	1.8	3.8					
% Std Dev				27.9	16.7	11.9	17.8					
W 53	Irrad	1660	105	69.4	8.0	7.2	12.7	2	4/26/68	1.8(11)	3.30(15)	5.80(15)
W 54			105	64.4	7.6	7.4	11.9	2	5/6/68	1.9(11)	3.40(15)	6.00(15)
W 56			105	77.4	7.3	7.0	13.3	2	5/16/68	1.9(11)	3.50(15)	6.10(15)
Average				70.4	7.6	7.2	12.6					
Std Dev				6.6	0.4	0.2	0.7					
% Std Dev				9.3	4.6	2.8	5.6					
W 57	Irrad	1660	105	73.8	7.3	7.3	13.5	1	4/22/68	7.4(11)	5.60(16)	1.38(17)
W 58			105	71.3	8.5	8.2	13.3	1	5/2/68	7.6(11)	5.80(16)	1.42(17)
W 60			105	48.7	8.8	8.4	13.6	1	5/8/68	7.7(11)	6.00(16)	1.50(17)
Average				64.6	8.2	8.0	13.4					
Std Dev				13.8	0.8	0.6	0.2					
% Std Dev				21.4	9.7	7.4	1.1					
W 61	Irrad	1660	105	60.7	6.1	5.4	13.5	2	4/19/68	2.2(12)	5.75(17)	2.05(18)
W 62			105	41.4	7.3	6.9	13.1	2	4/28/68	2.2(12)	6.10(17)	2.12(18)
W 63			105	66.1	5.3	4.9	9.2	2	5/12/68	2.3(12)	6.30(17)	2.23(18)
Average				56.0	6.2	5.7	11.9					
Std Dev				13.0	1.0	1.0	2.4					
% Std Dev				23.2	16.1	18.2	19.9					

[a] Not included in average

Table 6-12 (Cont'd)

Specimen Number	Condition	Test Temp (°R)	Stress (ksi)	Time to Failure (h)	% Elongation		% Area Reduct (Bench)	Frac Location	Date Failed	Radiation Exposure		
										Gamma Dose	Neutron Fluence (n/cm^2)	
					Bench	Chart				[ergs/g(C)]	E > 1.0 MeV	E < 0.48 eV
WS 01	Control	1860	70-80	24.8	22.0	20.8	26.6	1	6/1/68			
WS 02			70-80	24.5	29.9	27.2	31.4	2	6/4/68			
Average				24.7	30.0	24.0	29.0					
Std Dev				0.2	5.6	4.5	3.4					
% Std Dev				0.9	21.5	18.9	11.7					
WS 03	Irrad	1860	70	15.7	6.7	5.6	9.6	2	6/5/68	2.0(11)	3.60(15)	6.20(15)
WS 04			70	12.8	7.8	6.4	10.4	2	6/7/68	2.0(11)	3.68(15)	6.36(15)
Average				14.3	7.3	6.0	10.0					
Std Dev				2.1	0.8	0.6	0.6					
% Std Dev				14.4	10.7	9.4	5.7					
WS 05	Irrad	1860	70	14.2	7.4	5.3	9.3	2	6/8/68	7.8(11)	6.10(16)	1.53(17)
WS 06			70	11.9	5.4	4.2	5.8	2	6/6/68	8.0(11)	6.20(16)	1.58(17)
Average				13.1	6.4	4.8	7.6					
Std Dev				1.6	1.4	0.8	2.5					
% Std Dev				12.5	22.1	16.4	32.8					

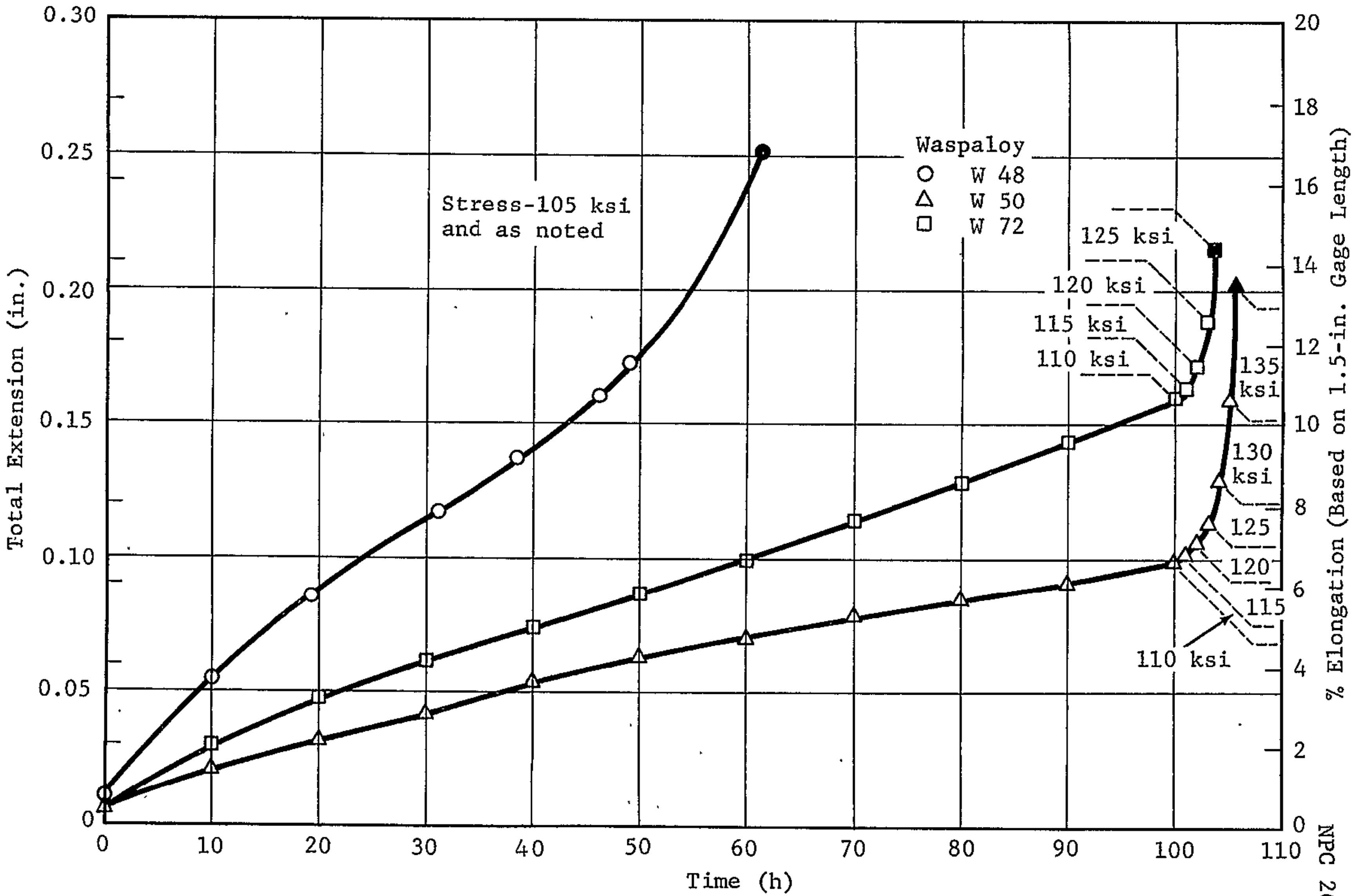


Figure 6-79 Stress-Rupture Characteristics of Waspaloy: Unnotched Control Specimens Tested at 1660°R

NPC 26,836

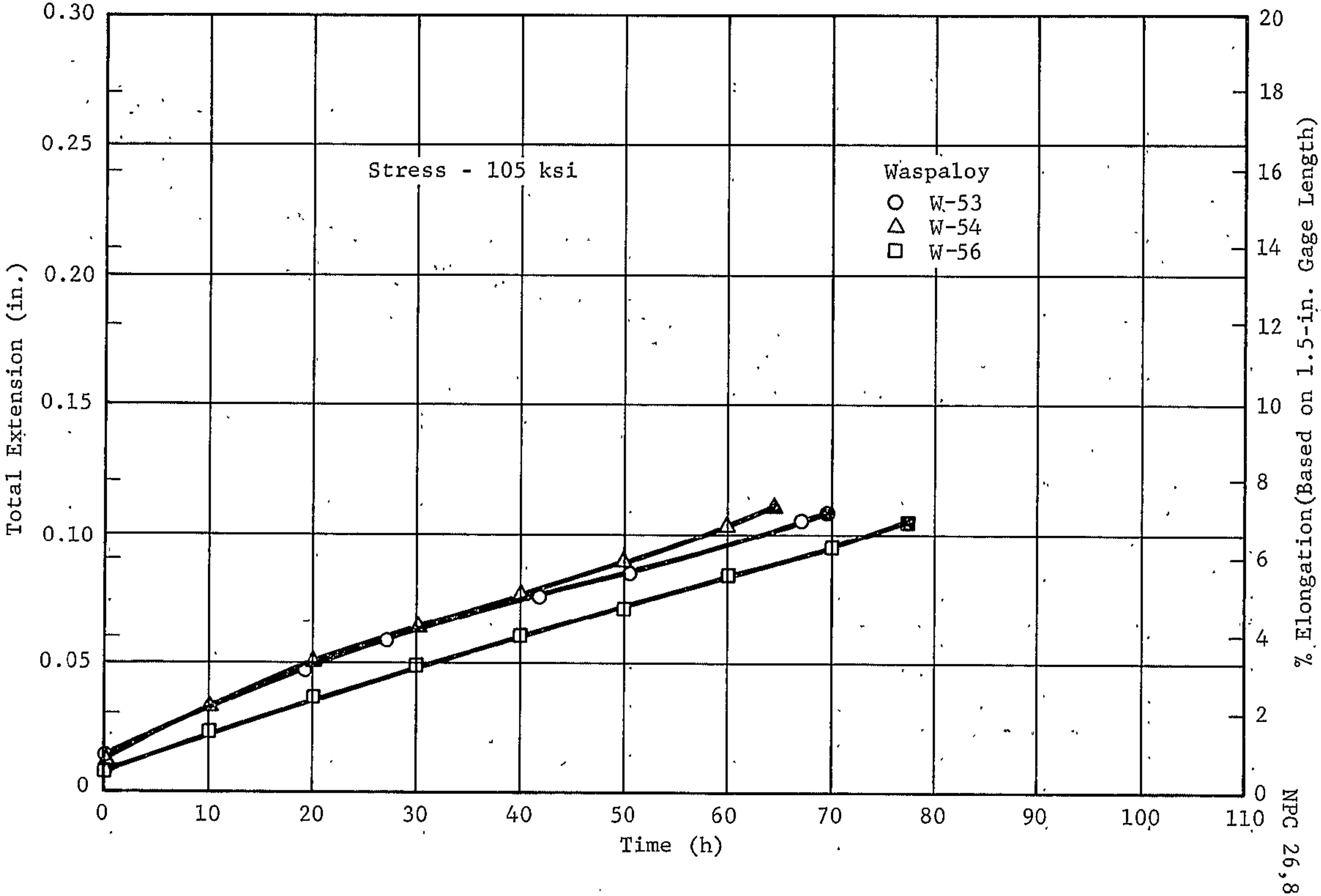
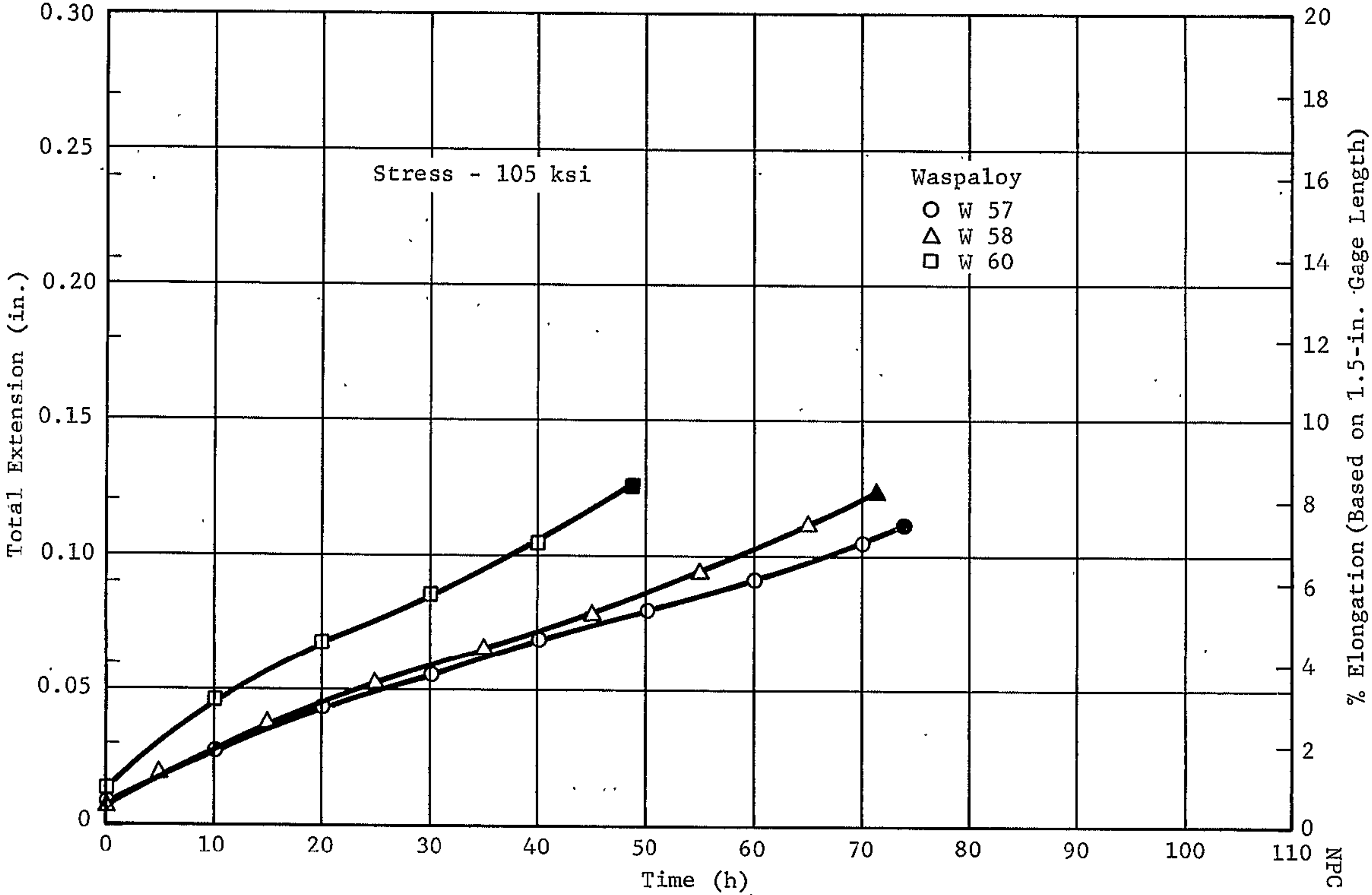
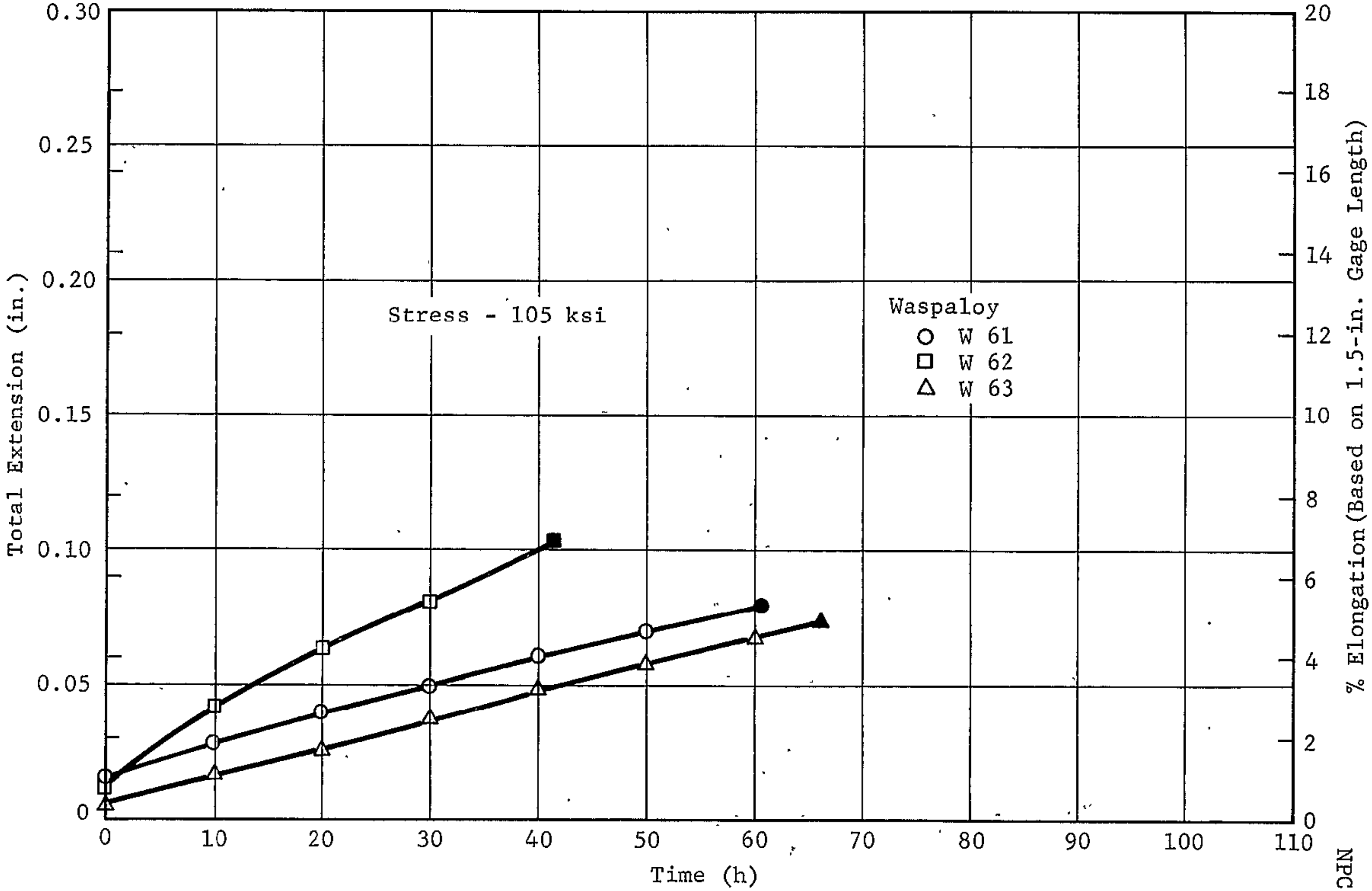


Figure 6-80 Stress-Rupture Characteristics of Waspaloy: Unnotched Specimens Irradiated to 6.0×10^{15} n/cm^2 (Thermal) and Tested at 1660°R



NPC 26,838

Figure 6-81 Stress-Rupture Characteristics of Waspaloy: Unnotched Specimens Irradiated to 1.4×10^{17} n/cm^2 (Thermal) and Tested at 1660°R



NPC 26,839

Figure 6-82 Stress-Rupture Characteristics of Waspaloy: Unnotched Specimens Irradiated to 2.1 x 10^{18} n/cm^2 (Thermal) and Tested at 1660^{o}R

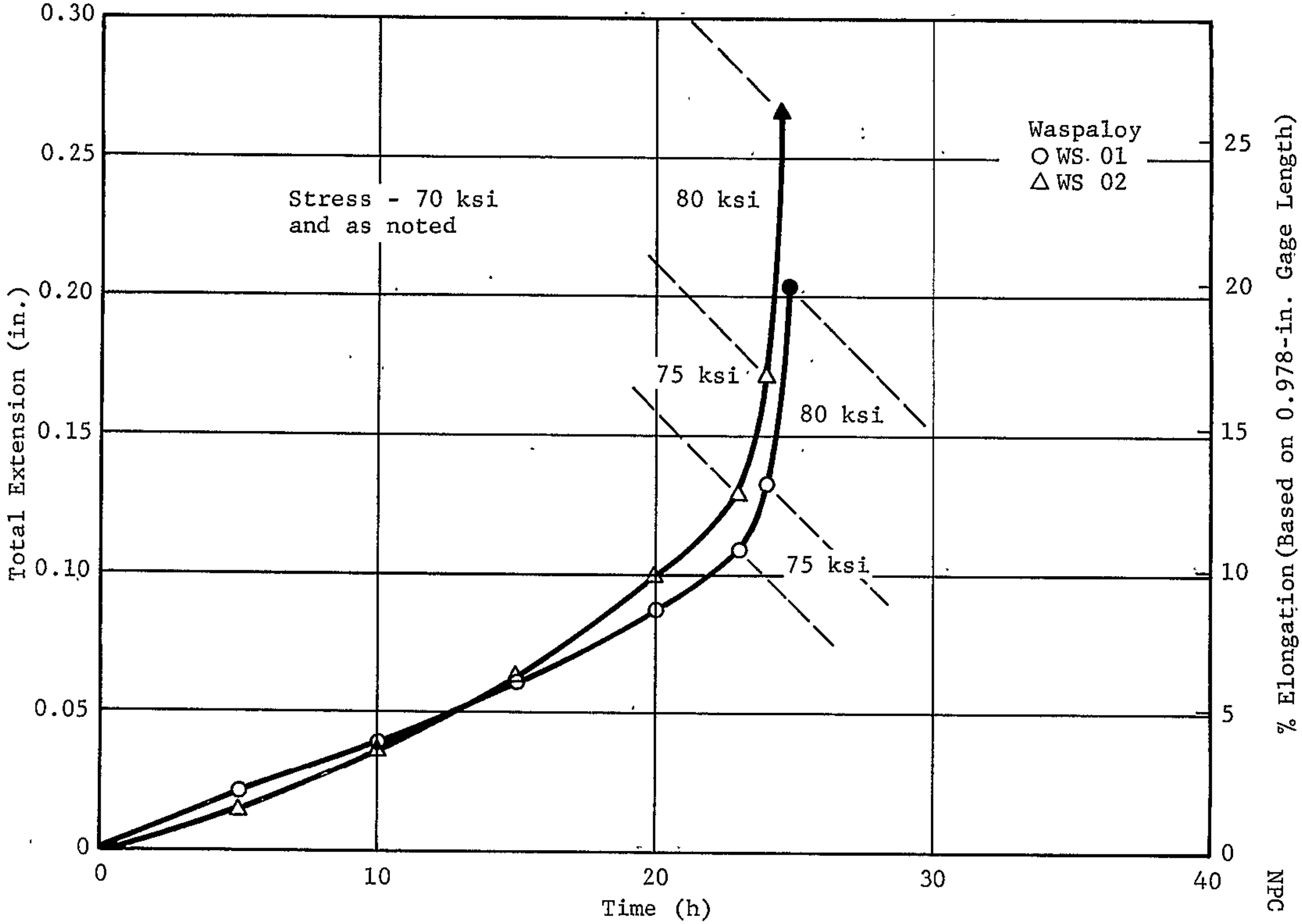


Figure 6-83 Stress-Rupture Characteristics of Waspaloy: Combination Control Specimens Tested at 1860°R

NPC 26,840

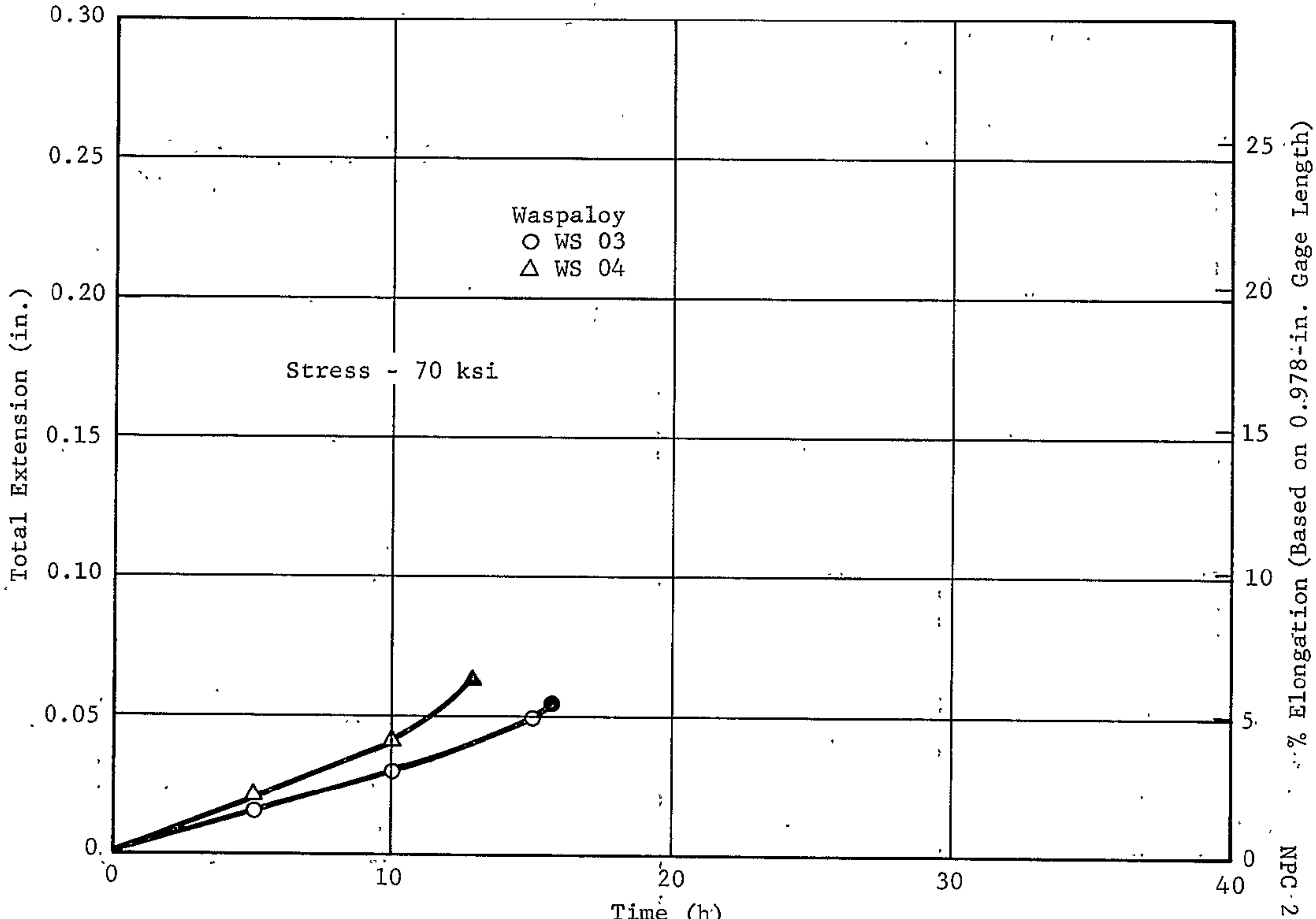
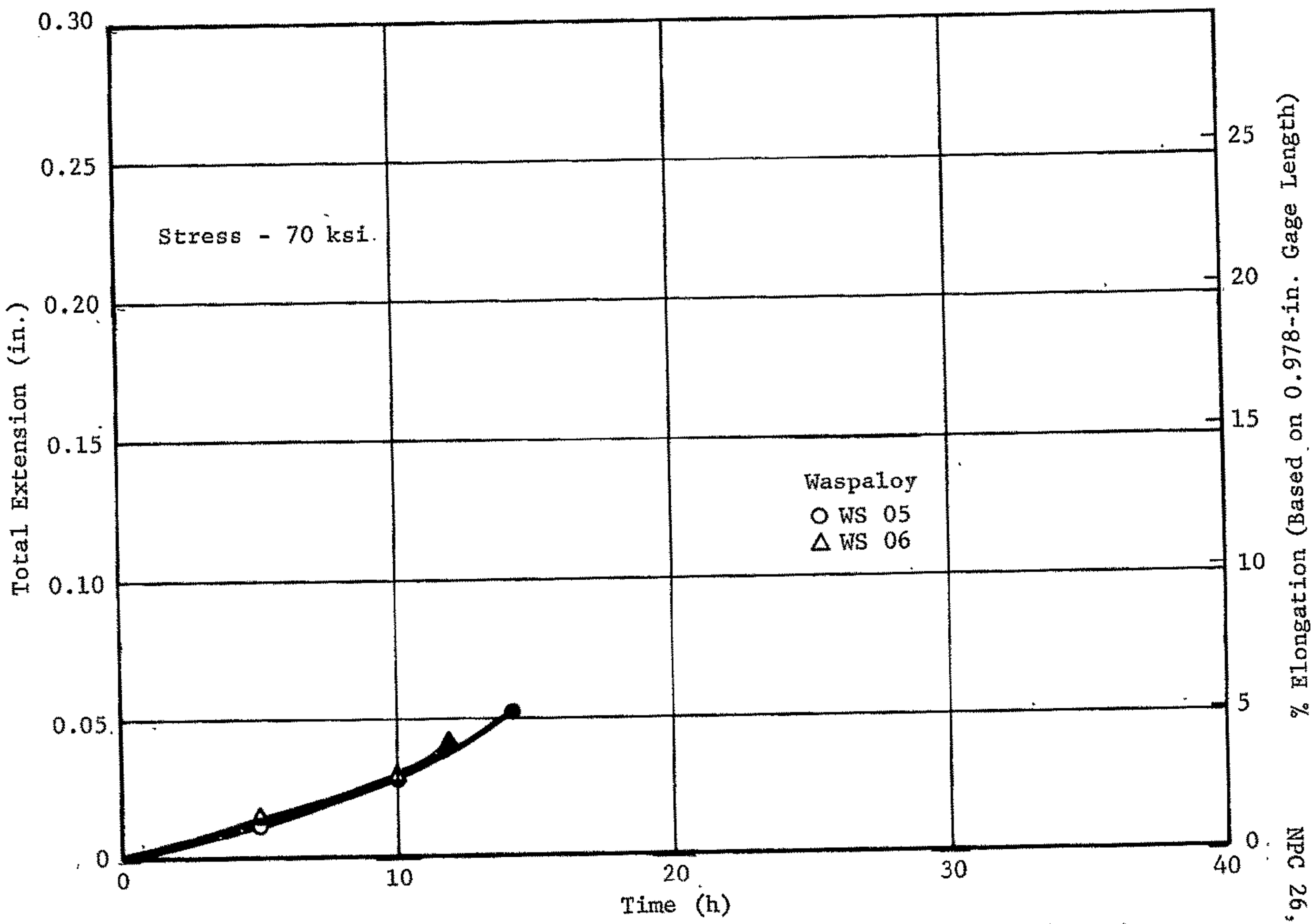


Figure 6-84 Stress-Rupture Characteristics of Waspaloy: Combination Specimens Irradiated to 6.3×10^{15} n/cm^2 (Thermal) and Tested at 1860°R



NPC 26,842

Figure 6-85 Stress-Rupture Characteristics of Waspaloy: Combination Specimens Irradiated to 1.6 x 10^{17} n/cm^2 (Thermal) and Tested at 1860°R

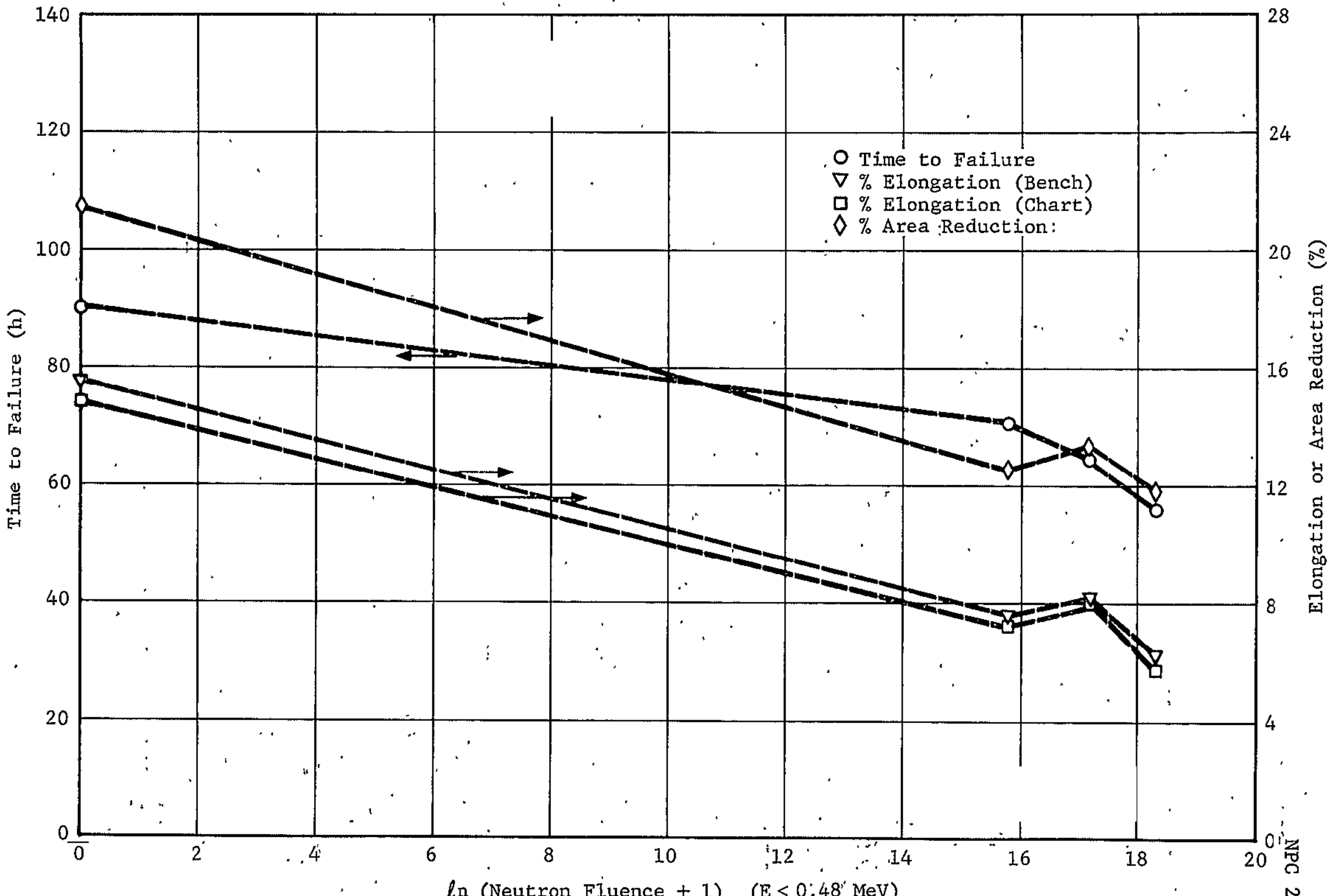


Figure 6-86 Effect of Neutron Exposure on the Stress-Rupture Properties of Waspaloy Round-Unnotched Specimens

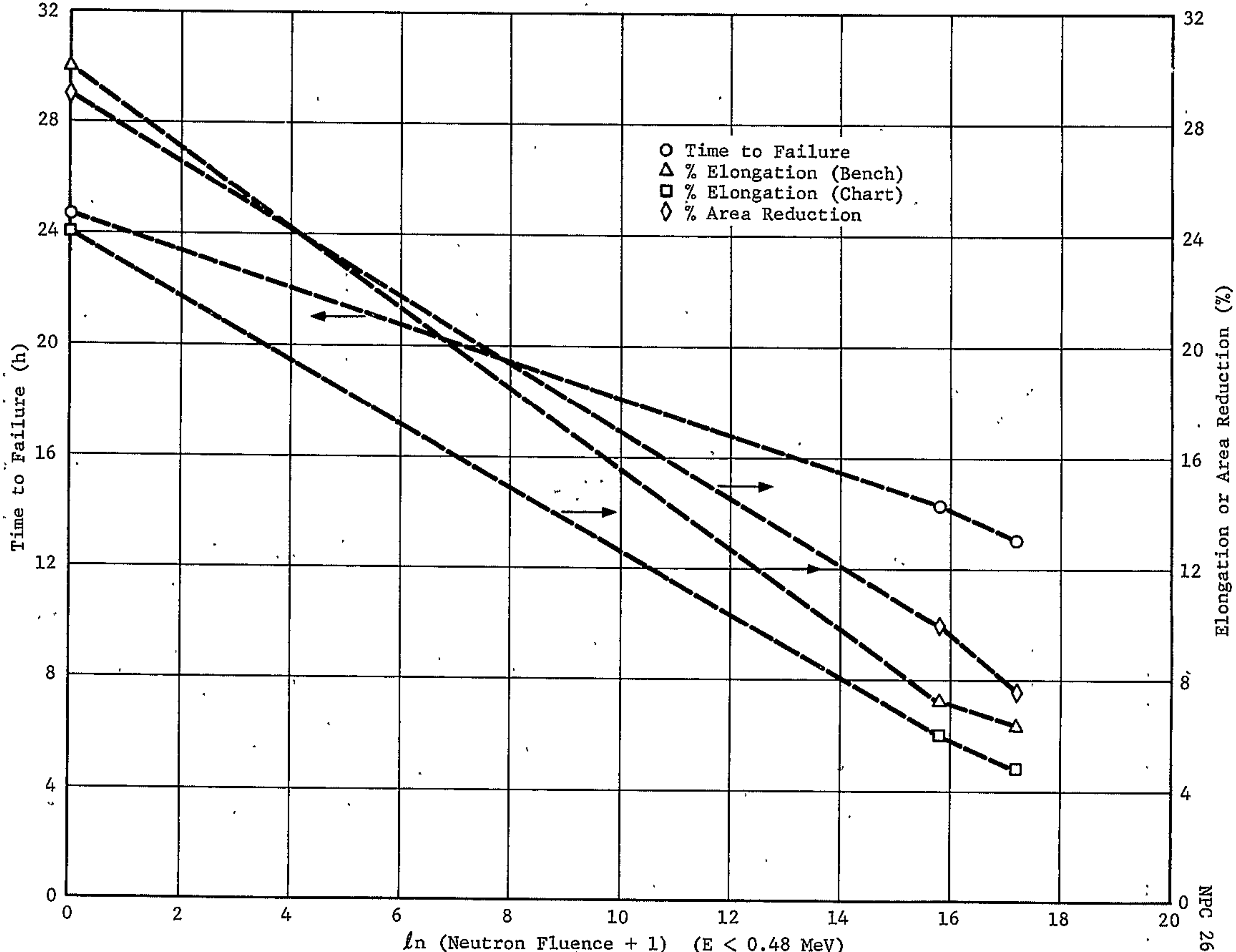


Figure 6-87 Effect of Neutron Exposure on the Stress-Rupture Properties of Waspaloy Combination-Notched Specimens

NPC 26,929

Section 6.6

Presentation of
Inconel 718 Stress-Rupture Data

INDEX TO INCONEL 718 STRESS-RUPTURE DATA

Configuration and Condition	Test Temp (°R)	Stress (ksi)	Spec. No.[a]	Stress-Rupture Data Table	Stress-Rupture Data Page	Stress-Rupture Curves Fig.	Stress-Rupture Curves Page	Effect of Radiation Fig.	Effect of Radiation Page
Round-Unnotched									
Control	1660	115	N 44	6-13	6-144	-	-	-	-
		110	N 45			6-88	6-146	6-95	6-153
		110	N 46						
		110	N 57						
Low Irrad	1660	110	N 47			6-89	6-147		
		110	N 48						
		110	N 49						
Medium Irrad	1660	110	N 50			6-90	6-148		
		110	N 51						
		110	N 52						
High Irrad	1660	110	N 53			6-91	6-149		
		110	N 55						
		110	N 56						
Low Irrad	1660	110	L 08		6-145	6-92	6-150		
Medium Irrad	1660	110	L 03			6-93	6-151		
		110	L 11						
		110	L 13						
Combination-Notched									
Control	1760	75	NS 01			-	-	-	-
		75-110	NS 02			6-94	6-152	6-96	6-154
		75-110	NS 07						
Low Irrad	1760	75	NS 03			-	-		
		75-95	NS 04			-	-		
Medium Irrad	1760	75	NS 05			-	-		
		75	NS 06			-	-		

[a] N, 37 ppm boron; L, 0.6 ppm boron

PRECEDING PAGE BLANK NOT FILMED

Table 6-13

STRESS-RUPTURE TEST DATA FOR INDIVIDUAL SPECIMENS OF INCONEL 718

Specimen Configuration: round-unnotched (N) - AGC Dwg. 1134298-1
combination-notched (NS) - AGC Dwg. 1134453 Data to be used for material evaluation only. Do not use for design.

Specimen Number [a]	Condition	Test Temp (^oR)	Stress (ksi)	Time to Failure (h)	% Elongation		% Area Reduct (Bench)	Frac Location	Date Failed	Radiation Exposure		
										Gamma Dose [ergs/g(C)]	Neutron Fluence (n/cm^2)	
					Bench	Chart					E > 1.0 MeV	E < 0.48 eV
N 44[b].	Control	1660	115	29.1	3.4	3.0	9.6	1	3/19/68			
N 45			110	69.4	7.1	6.9	15.1	4	4/1/68			
N 46			110	54.7	7.2	7.2	16.5	4	4/4/68			
N 57			110	51.9	3.3	3.3	11.9	4	5/15/68			
Average				58.7	5.9	5.3	14.5					
Std Dev				9.4	2.2	2.5	2.4					
% Std Dev				16.0	37.9	46.1	16.3					
N 47	Irrad	1660	110	49.9	4.2	4.1	13.9	4	4/14/68	2.0(11)	3.75(15)	6.39(15)
N 48			110	66.5	4.5	3.9	9.6	2	4/24/68	2.1(11)	3.80(15)	6.40(15)
N 49			110	50.1	4.2	-	10.9	1	4/27/68	2.1(11)	3.80(15)	6.40(15)
Average				55.5	4.3	4.0	11.5					
Std Dev				9.5	0.2	0.1	2.2					
% Std Dev				17.2	4.0	3.5	19.2					
N 50	Irrad	1660	110	41.2	2.2	1.1	9.5	2	4/19/68	6.5(11)	4.25(16)	1.02(17)
N 51			110	38.3	2.4	1.7	9.5	3	5/1/68	6.6(11)	4.28(16)	1.03(17)
N 52			110	28.9	2.1	1.1	11.4	1	5/3/68	6.6(11)	4.30(16)	1.06(17)
Average				36.1	2.2	1.3	10.1					
Std Dev				6.4	0.2	0.3	1.1					
% Std Dev				17.8	6.8	26.6	10.8					
N 53	Irrad	1660	110	11.8	1.4	0.3	7.0	1	4/20/68	2.3(12)	6.40(17)	2.29(18)
N 55			110	8.2	1.3	0.5	5.6	1	5/1/68	2.4(12)	6.55(17)	2.32(18)
N 56			110	13.2	1.3	0.2	8.7	2	5/7/68	2.4(12)	6.60(17)	2.37(18)
Average				11.1	1.3	0.3	7.1					
Std Dev				2.6	0.1	0.2	1.6					
% Std Dev				23.3	4.3	45.8	21.9					

[a] N, 37 ppm boron; L, 0.6 ppm boron

[b] Not included in average

Table 6-13 (Cont'd)

Specimen Number	Condition	Test Temp (°R)	Stress (ksi)	Time to Failure (h)	% Elongation		% Area Reduct (Bench)	Frac Loca-tion	Date Failed	Radiation Exposure		
										Gamma Dose [ergs/g(C)]	Neutron Fluence (n/cm^2)	
					Bench	Chart					E > 1.0 MeV	E < 0.48 eV
L 08	Irrad	1660	110	51.8	4.4	3.3	8.8	2	4/11/68	2.0(11)	3.75(15)	6.37(15)
L 03[b]	Irrad	1660	110	5.0	1.9	0.3	6.9	4	5/7/68	9.4(11)	9.00(16)	2.40(17)
L 11			110	38.2	3.4	1.7	19.0	2	4/17/68	6.6(11)	4.25(16)	1.03(17)
L 13			110	51.7	3.1	2.0	8.4	3	5/11/68	7.1(11)	5.35(16)	1.28(17)
Average				45.0	3.3	1.9	13.7					
Std Dev				9.6	0.2	0.2	7.5					
% Std Dev				21.2	6.5	11.5	54.7					
NS 01[b]	Control	1760	75	0.2	1.0	0.0	-	N	5/22/68			
NS 02			75-110	29.8	12.1	10.9	14.2	2	5/25/68			
NS 07			75-110	29.7	26.7	25.7	26.1	1	5/28/68			
Average				29.8	19.4	18.3	20.2					
Std Dev				0.1	10.3	10.5	8.4					
% Std Dev				0.2	53.2	57.2	41.8					
NS 03	Irrad	1760	75	21.3	1.2	0.4	-	N	6/1/68	2.1(11)	3.80(15)	6.40(15)
NS 04			75-95	26.5	1.6	-	-	N	6/5/68	2.1(11)	3.80(15)	6.39(15)
Average				23.9	1.4	-	-					
Std Dev				3.7	0.3	-	-					
% Std Dev				15.4	20.2	-	-					
NS 05	Irrad	1760	75	1.9	0.8	0.1	-	N	6/4/68	8.0(11)	6.25(16)	1.60(17)
NS 06			75	0.8	0.9	0.1	-	N	6/6/68	8.0(11)	6.20(16)	1.58(17)
Average				1.4	0.9	0.1						
Std Dev				0.8	0.1	0						
% Std Dev				57.6	8.3	0						

[b]Not included in average

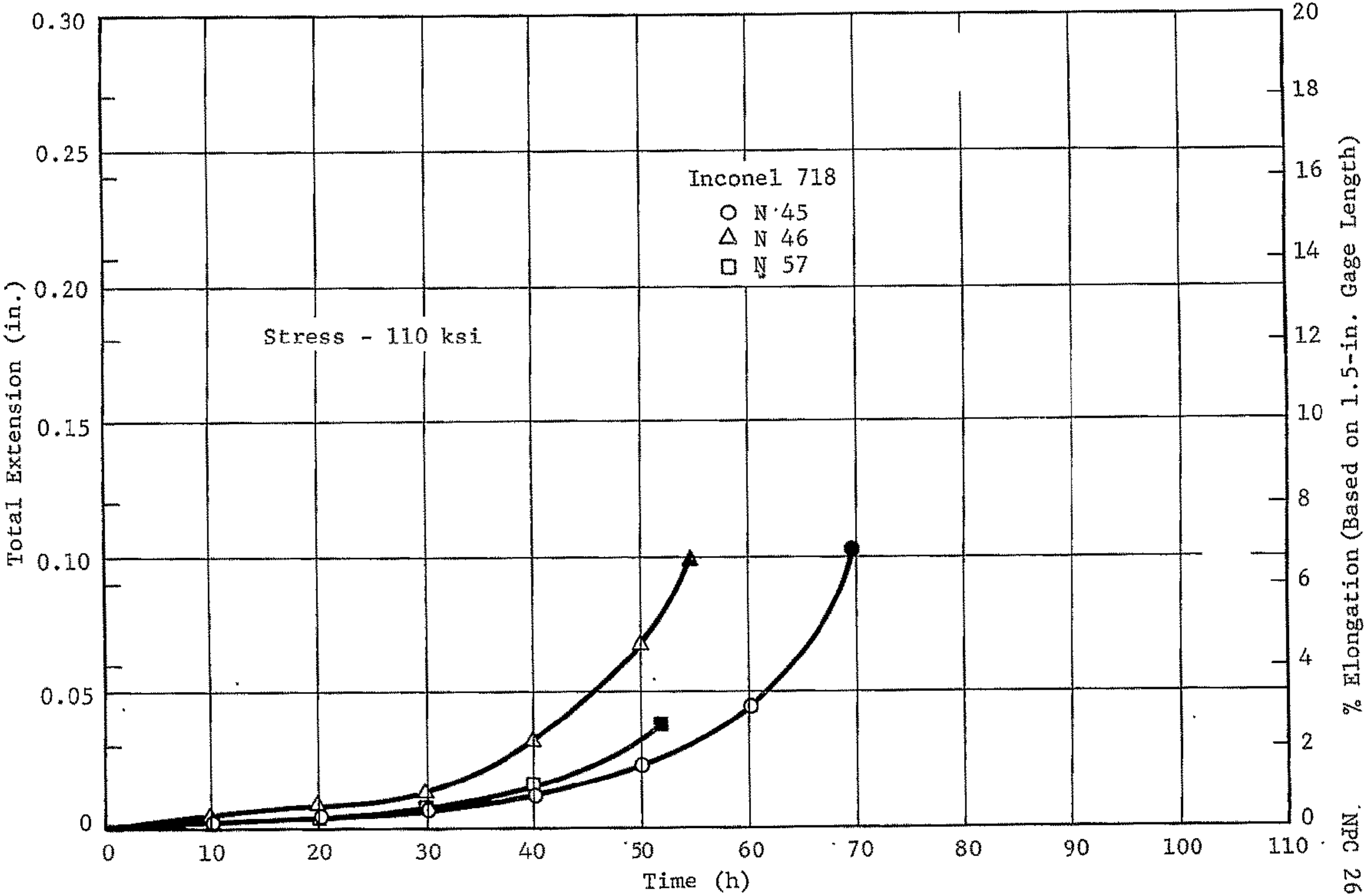
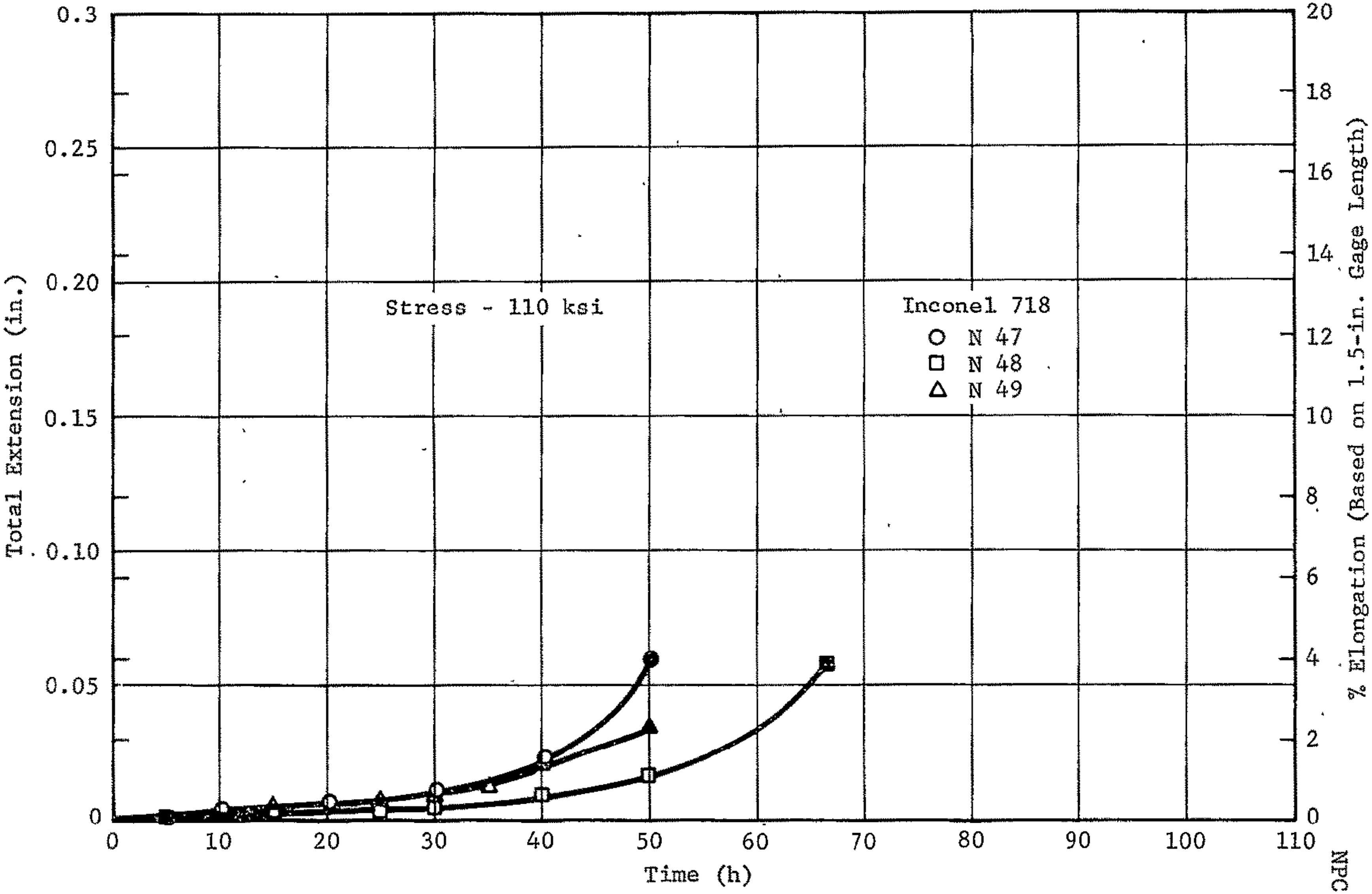
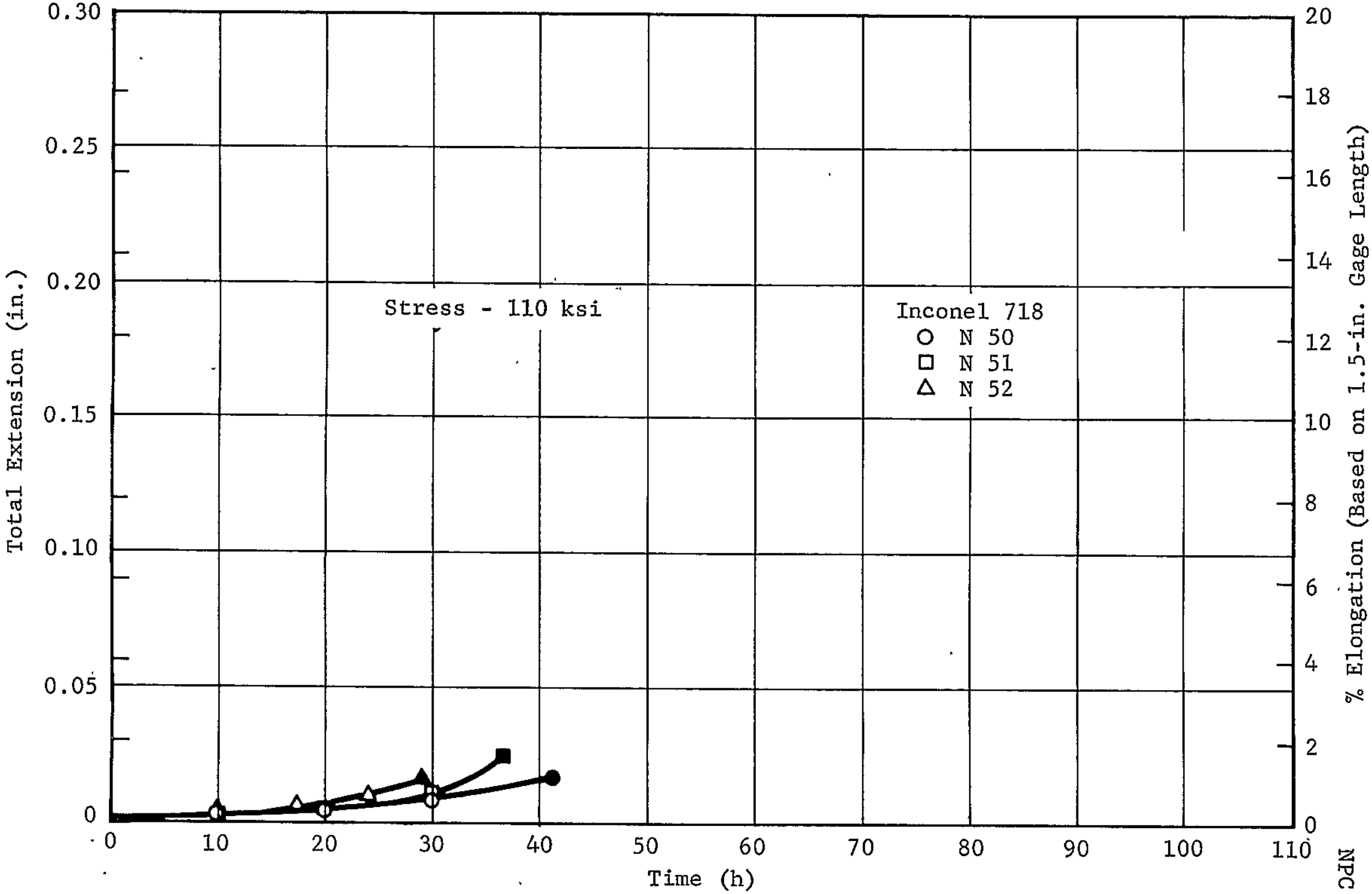


Figure 6-88 Stress-Rupture Characteristics of Inconel 718 (37 ppm Boron): Unnotched Control Specimens Tested at 1660°R



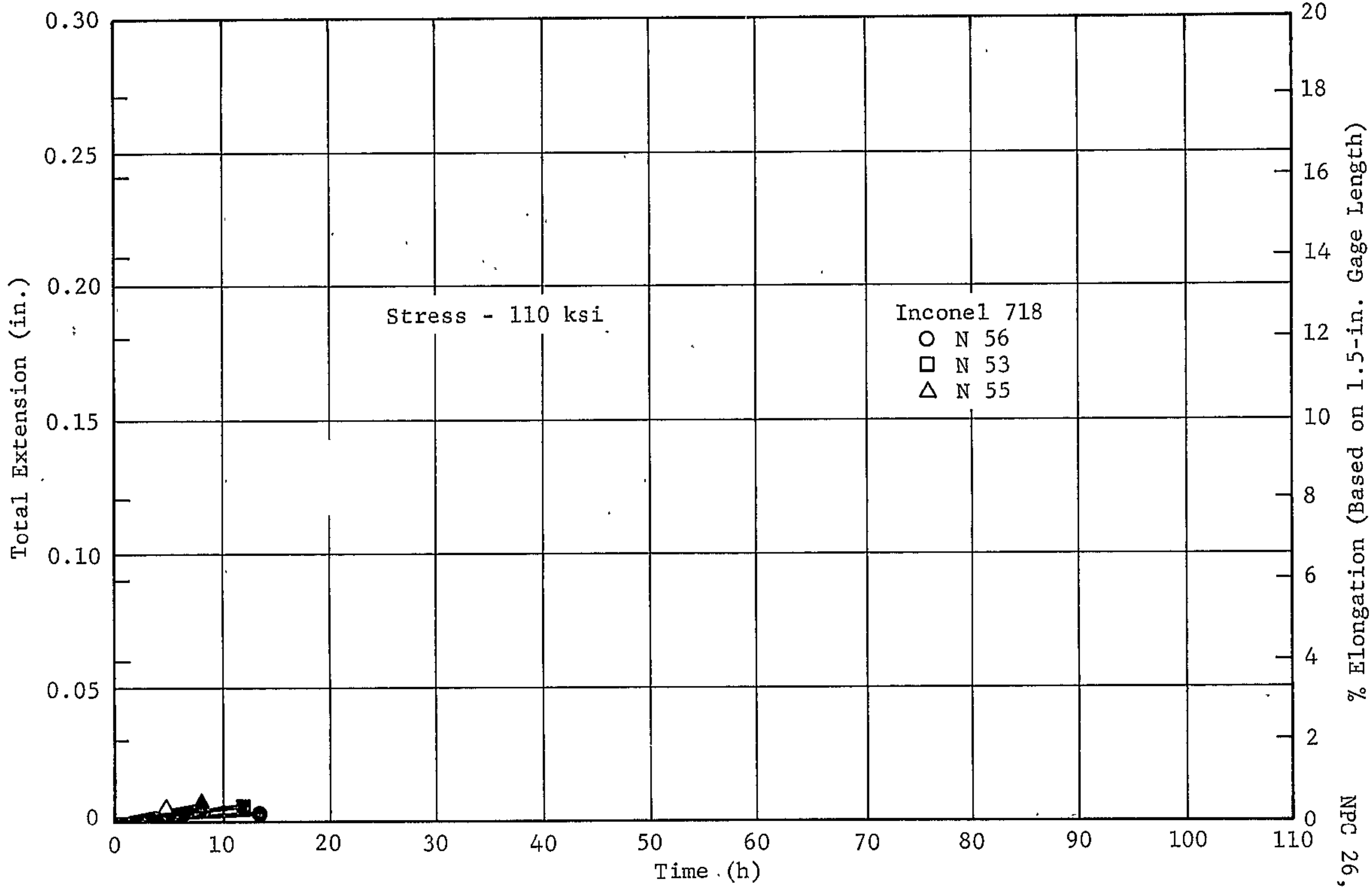
NPC 26,844

Figure 6-89 Stress-Rupture Characteristics of Inconel 718 (37 ppm Boron): Unnotched Specimens Irradiated to 6.4×10^{15} n/cm^2 (Thermal) and Tested at 1660°R



NPC 26,845

Figure 6-90 Stress-Rupture Characteristics of Inconel 718 (37 ppm Boron): Unnotched Specimens Irradiated to 1.0 x 10^{17} n/cm^2 (Thermal) and Tested at 1660°R



NPC 26,846

Figure 6-91 Stress-Rupture Characteristics of Inconel 718 (37 ppm Boron): Unnotched Specimens Irradiated to 2.3×10^{18} n/cm^2 (Thermal) and Tested at 1660^oR

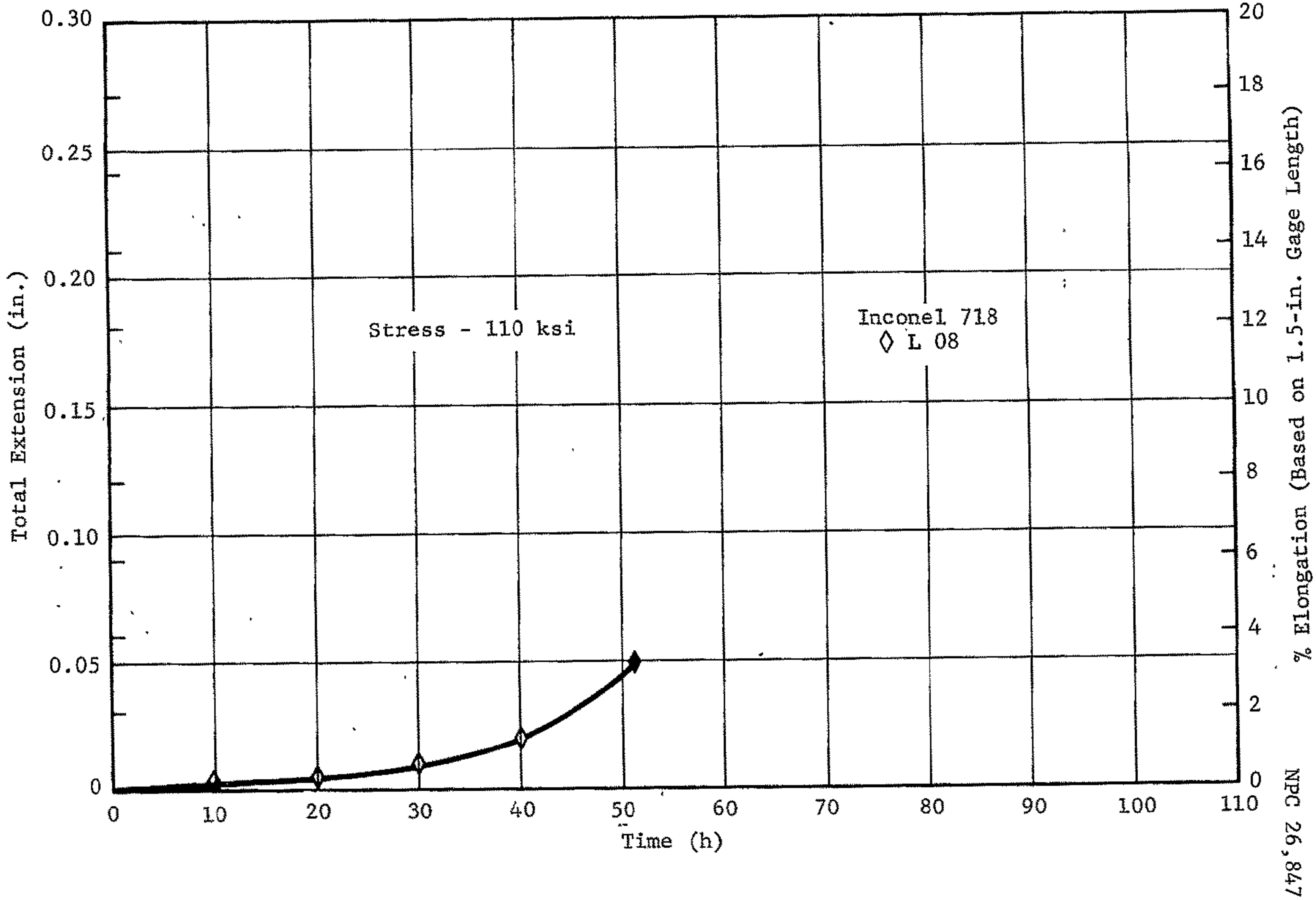
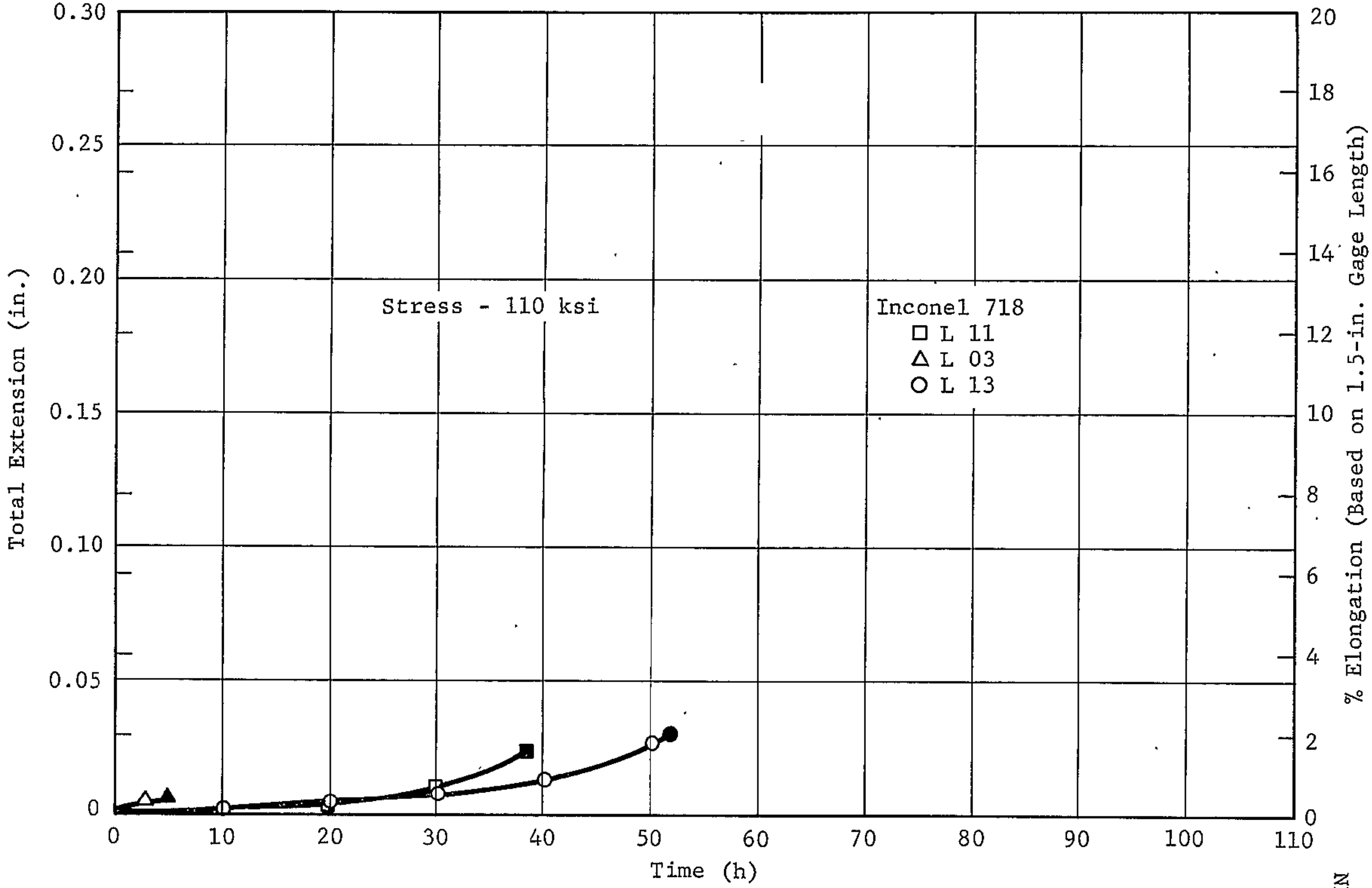


Figure 6-92 Stress-Rupture Characteristics of Inconel 718 (0.6 ppm Boron): Unnotched Specimens Irradiated to 6.4×10^{15} n/cm^2 (Thermal) and Tested at 1660°R



NPC 26,848

Figure 6-93 Stress-Rupture Characteristics of Inconel 718 (0.6 ppm Boron): Unnotched Specimens Irradiated to 1.6 x 10^{17} n/cm^2 (Thermal) and Tested at 1660^{o}R

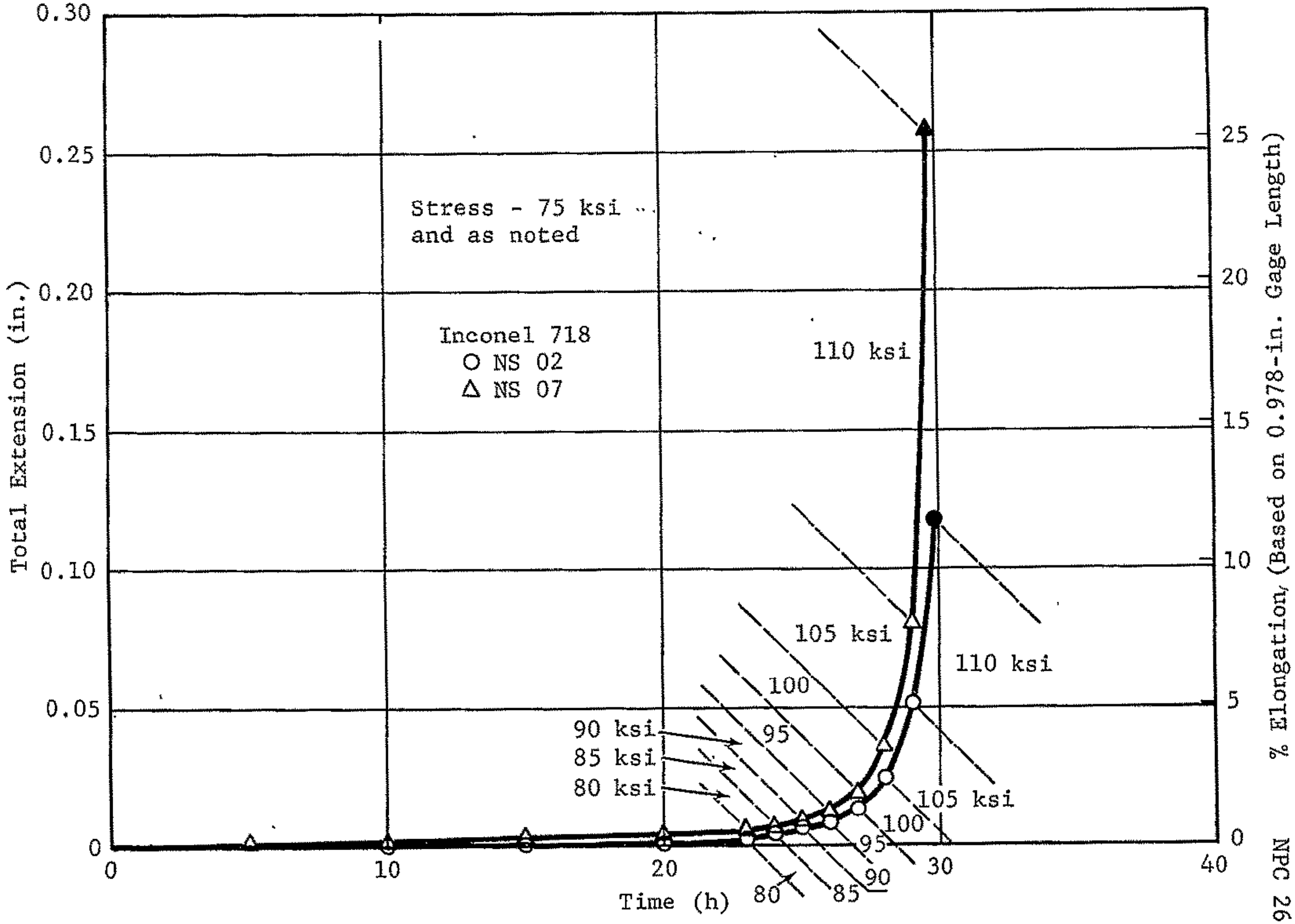
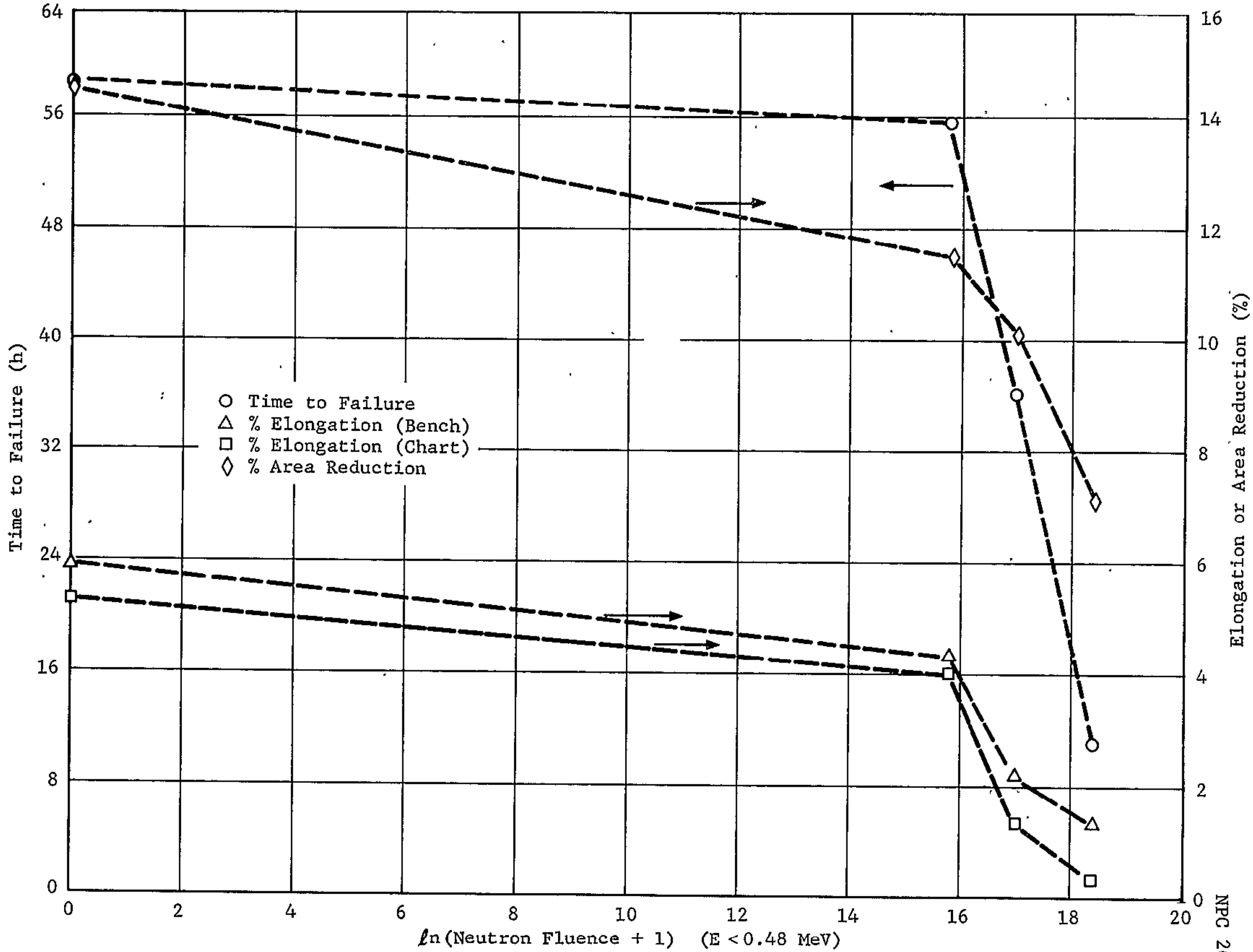


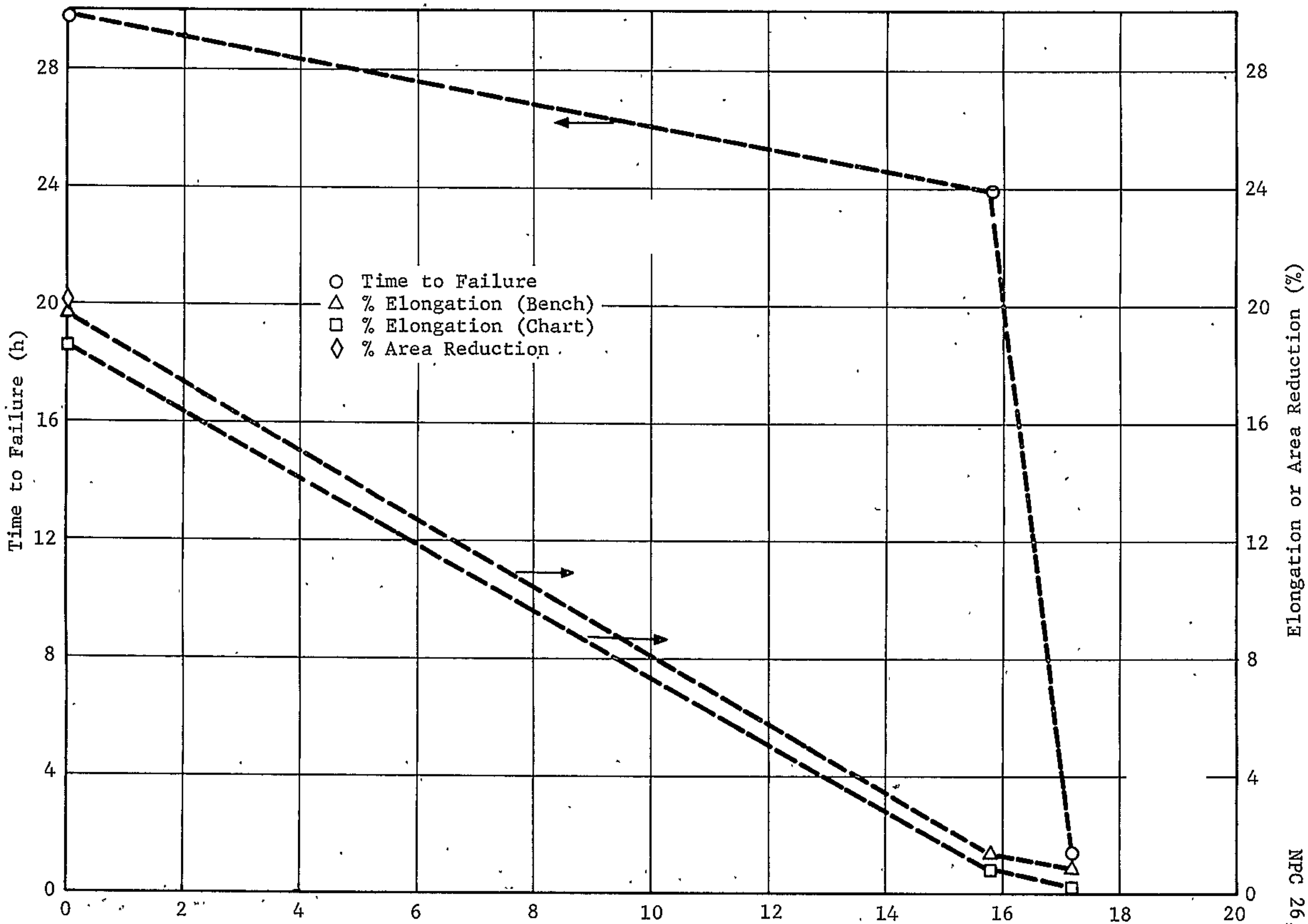
Figure 6-94 Stress-Rupture Characteristics of Inconel 718 (37 ppm Boron): Combination Control Specimens Tested at 1760°R

NPC 26,849



NPC 26,935

Figure 6-95 Effect of Neutron Exposure on the Stress-Rupture Properties of Inconel 718 (37 ppm B) Round-Unnotched Specimens



ℓn(Neutron Fluence + 1) (E < 0.48 MeV)

Figure 6-96 Effect of Neutron Exposure on the Stress-Rupture Properties of Inconel 718 (37 ppm B) Combination-Notched Specimens

NPC 26,936

APPENDIX A

DOSIMETRY PROCEDURES

The radiation exposure at the location of the specimen racks was monitored with several packets of foils, each packet containing a sulfur pellet and a pair (unshielded and cadmium shielded) of phosphorus pellets. Sulfur is used to measure the fluence of neutrons having an energy greater than 2.9 MeV; this is then converted to the reported fluence of neutrons with energies greater than 1.0 MeV by multiplying by an analytically determined factor of 2.82. The fluence of thermal neutrons ($E < 0.48$ eV) is determined with the phosphorus by the cadmium-difference method. Standardized counting and data-reduction procedures were employed in converting activation of the pellets to neutron fluences.

Some months after completion of the GTR-21 irradiation, the opportunity arose to obtain additional dosimetry data in two irradiations performed for the purpose of mapping the GTR radiation field. The data from the mapping experiments were relied on heavily in determining the exposure of the individual specimens of both the cryogenic and high-temperature materials.

A-1 Cryogenic Materials

For the GTR-21 irradiation, the cryogenic-specimen rack (Fig. 3-5) was instrumented with four packets of dosimeters - two in front and two at the rear. The fluence of thermal neutrons and fast (E > 1.0 MeV) neutrons, as determined from phosphorus and sulfur detectors, respectively, were:

Location	Neutron Fluence (10^{16} n/cm^2) Thermal	Fast
Front, north	2.59	32.5
Front, south	1.56	10.8
Rear, north	1.89	13.1
Rear, south	2.74	8.31

For the mapping irradiation, the aluminum and Hastelloy X specimens that had been irradiated and tested in GTR-21 were reinstalled in the irradiation rack in the same configuration as during the GTR-21 irradiation. A sulfur pellet was attached to the gage section of half of the round specimens and near the notch on half of the flat specimens; the pellets were placed on alternate specimens in the array. In addition, four packets, each containing a sulfur pellet and a pair of phosphorus pellets, were attached to the rack at positions approximately the same as those of the GTR-21 packets. The irradiation took place on 13 June 1968 at a reactor power level of 5 MW for 2 hours.

The specimen rack was irradiated in air (not in a dewar) at a location that corresponded only roughly to that of the GTR-21 irradiation. The data from the two irradiations are therefore not directly correlatable without normalization. A normalization factor was determined by comparing the fluences for the two irradiations at the four packet locations. From the mapping irradiation, the thermal- and fast-neutron fluences (adjusted to 2310 MWh) were:

Location	Neutron Fluence (10^{16} n/cm^2) Thermal	Fast
Front, north	0.82	57.6
Front, south	1.53	13.0
Rear, north	2.28	28.3
Rear, south	2.66	15.7

Comparing the fast-neutron fluences above with those given earlier, it is observed that the difference is approximately a factor of 2 at all the locations except the south front. Since there was a question as to the actual location of the south front packet during the specimen irradiation, the data for this location were disregarded and the average of the ratios from the other three locations was taken as the normalization factor. This average ratio, 1.95, was used to adjust the sulfur pellet data from the mapping run to an appropriate fluence for each specimen to which a sulfur pellet was attached.

The fluences thus determined were plotted as a function of position in the specimen array, and fast-neutron fluences for the remaining specimens were obtained by interpolation and extrapolation. The results of these manipulations are tabulated in Table A-1, which gives the fast-neutron fluence (E > 1.0 MeV) for each

Table A-1

FAST-NEUTRON FLUENCE ($E > 1.0$ MeV) FOR SPECIMENS IRRADIATED IN LIQUID NITROGEN

(Based on normalized mapping data)

Specimen No.	Fast-Neutron Fluence (10^{16} n/cm^2)	Specimen No.	Fast-Neutron Fluence (10^{16} n/cm^2)
HW 05	8.5	BW 04	10.7
H 05	8.5[a]	B 05	9.7[a]
A 07	8.4	HW 08	15.1[a]
AW 08	8.9[a]	H 08	14.3
A 12	8.3	AW 07	13.5[a]
AW 04	8.5[a]	A 11	12.7
A 05	8.7	AW 12	12.1[a]
BW 06	9.0[a]	A 04	11.6
HW 06	10.1[a]	BW 05	11.3[a]
H 06	10.2	B 06	11.1
A 08	10.2[a]	A 18	18.0
AW 09	10.2	B 12	17.0[a]
AW 10	9.8[a]	B 13	15.0[a]
AW 05	9.5	BW 14	14.0[a]
A 06	9.1[a]	A 19	25.0[a]
B 04	8.8	A 20	22.0
HW 07	12.1	B 14	17.0[a]
H 07	12.1[a]	BW 15	15.0
A 09	12.2	AW 18	19.0
A 10	12.1[a]	BW 16	17.0[a]
AW 11	11.9	AW 19	21.0[a]
AW 06	11.5[a]	AW 21	19.0

[a]Interpolated or extrapolated

specimen irradiated in liquid nitrogen. The location of each specimen in the array is shown in Figure 3-9.

The precision of the data in Table A-1 is estimated to be ±9% for the round specimens and ±13% for the flat specimens, based on the following estimated errors:

Experimental factors in fluence determination (but not including cross section; see Section A-3)	±5%
Ratio of mapping data to GTR-21 data	±6%
Interpolation, round specimens	±5%
Interpolation, flat specimens	±10%

The thermal-neutron fluence for each specimen was estimated from the data obtained from the four sets of detectors irradiated during GTR-21. Except near the boral on the closet, the thermal-neutron flux in the irradiation cell does not change rapidly with position; consequently, a linear interpolation from front to rear of the specimen array was used to obtain the reported thermal-neutron fluences. The average of the four measured values is $(2.2 \pm 0.56) \times 10^{16}$ n/cm^2; the precision of the interpolated values should be somewhat better than the ±25% associated with the average value.

The gamma doses were estimated from neutron-to-gamma ratios measured in previous experiments with liquid-nitrogen dewars. It has been determined that a fluence ($E > 1.0$ MeV) of 8×10^5 n/cm^2

is accompanied by a gamma dose of roughly 1 erg/g(C). The reported gamma doses were therefore computed by dividing the fluences of Table A-1 by 8×10^5. Since the neutron-to-gamma ratio varies somewhat with location, this procedure is expected to give results valid only to within a factor of 2.

A-2 High-Temperature Materials

The specimen rack (Fig. 5-8) for the high-temperature materials was instrumented with seven dosimetry packets - three in front, three at the rear, and one at the center. The approximate location of the detectors with respect to the reactor core and the test specimens is shown in Figure A-1. Data were obtained from all seven pairs of phosphorus pellets; however, the three sulfur pellets nearest the reactor were destroyed by the irradiation. The thermal-neutron and fast-neutron ($E > 1.0$ MeV) fluences determined for the GTR-21 irradiation were:

Location	Neutron Fluence	
	Thermal	Fast
Front, west	4.17×10^{18}	-
Front, center	6.44×10^{18}	-
Front, east	7.05×10^{18}	-
Center	1.97×10^{17}	8.1×10^{16}
Rear, west	6.54×10^{15}	4.7×10^{15}
Rear, center	7.67×10^{15}	3.6×10^{15}
Rear, east	6.32×10^{15}	3.7×10^{15}

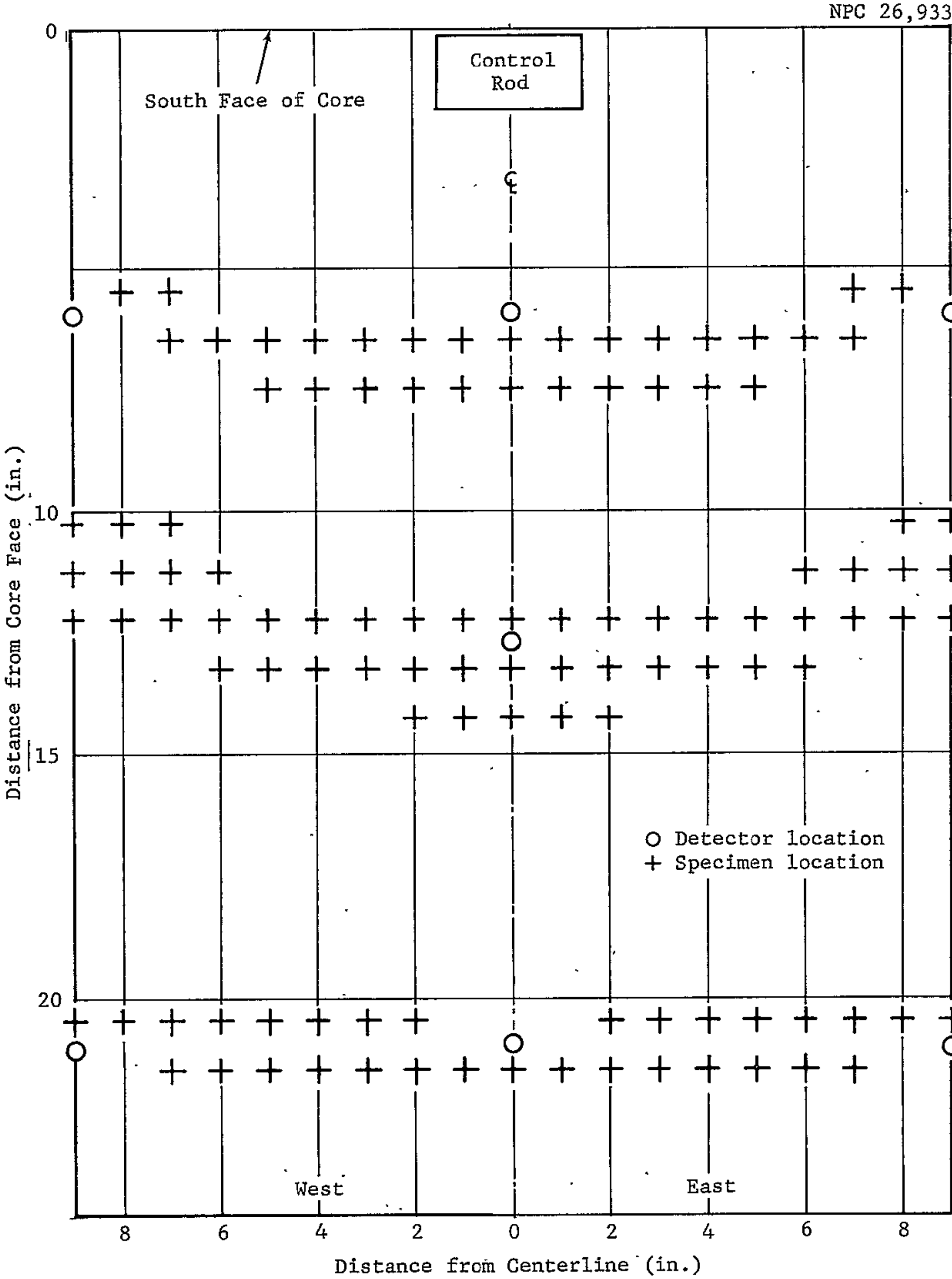


Figure A-1 Specimen Array for the GTR-21 Water-Irradiated High-Temperature Specimens

In preparation for the GTR-20 irradiation, the water irradiation position at the south face of the GTR core was mapped in five horizontal planes approximately 20 in. wide and extending 18.5 in. southward from the core face. Each of the five foil racks (planes) was laid out with a rectangular array of 40 sulfur pellets and 40 pairs (unshielded and shielded) of copper foils. An irradiation for 1 hour at 100 kW was made on 11 September 1968. Data from the foil rack irradiated at the GTR centerplane, corresponding to the location of the materials irradiated in GTR-21, have been used in estimating the neutron fluence to which each specimen was exposed.

The data obtained from the GTR-21 foils and the mapping dosimetry on the centerline and 10 in. east and 8 in. west of the centerline are plotted in Figure A-2. The centerline mapping data are also plotted in Figure A-3 as a function of (X + 11.5), where X is the distance from the core face and the 11.5 in. is a constant obtained by iteration which gives a minimum variance for a least-squares fit of a curve of the form

$$Y_i = a(X_i + 11.5)^b$$

Taking the logarithm of the above function gives the linear function

$$\ln Y_i = \ln a + b \ln(X_i + 11.5) \qquad \text{(A-1)}$$

which is amenable to fitting by least squares. This equation was used to estimate the precision in interpolating the fluence levels

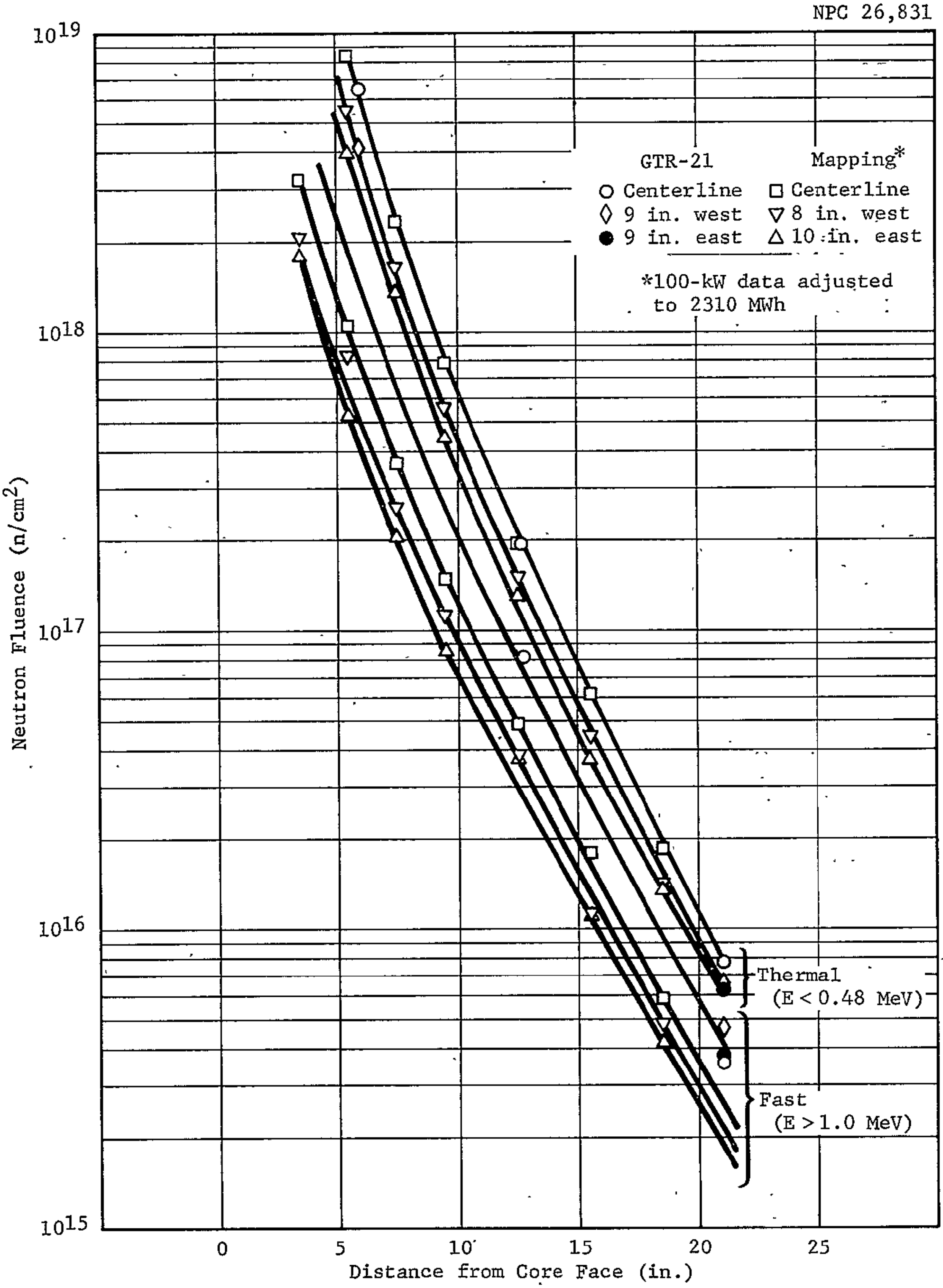


Figure A-2 Thermal- and Fast-Neutron Fluences as a Function of Distance from the South Face of the GTR

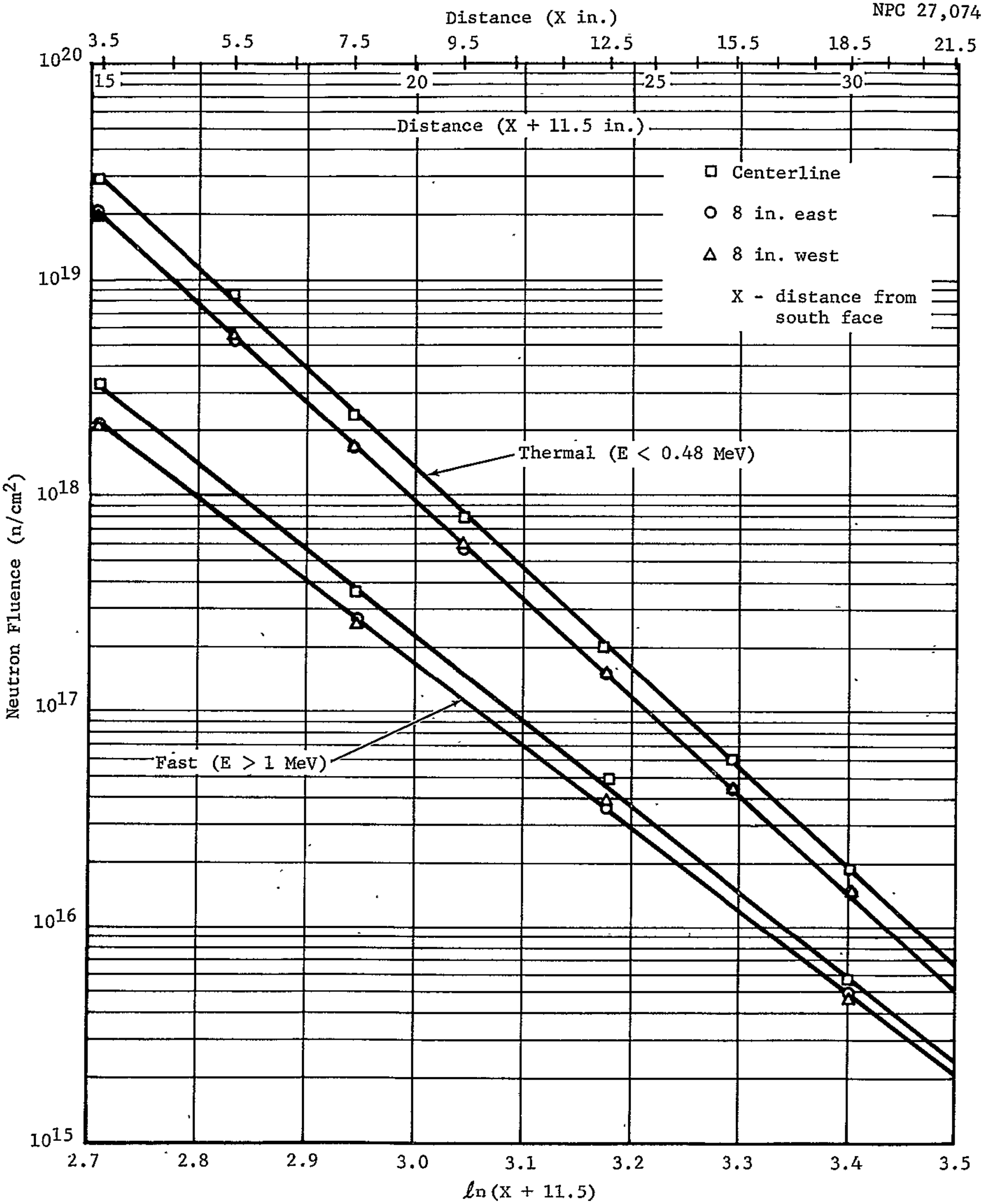


Figure A-3 Neutron Fluence Linearized as a Function of Distance from the South Face of the Core for the various positions within the radiation volume. It is felt that a measure of the precision of interpolation is more definable by this method than by graphical methods.

As seen from Figure A-2, the thermal-neutron fluence measured in the mapping irradiation, when adjusted to 2310 MWh, is in good agreement with comparable data from the GTR-21 irradiation. The mapping data have therefore been applied, without correction, to define the thermal-neutron field throughout the specimen array. In Figure A-4 the mapping data at various distances from the core face are plotted. The thermal-neutron fluences at other distances from the core at which specimens were located have been determined by interpolation of the curves of Figure A-2.

The estimated interpolation errors of the mapping data for thermal- and fast-neutron fluences are as follows:

Thermal-neutron fluence

Centerline	$\sigma = \pm 5\%$
8 in. east and west (combined)	$\sigma = \pm 4\%$

Fast-neutron fluence

Centerline	$\sigma = \pm 5\%$
8 in. east and west (combined)	$\sigma = \pm 8\%$

These precision estimates were calculated from the average sums of squares of deviations from the least-squares fit of Equation A-1 to the mapping data. It is assumed that these estimated standard deviations include the errors in fitting the chosen function, in the foil weight, and in counting the foils. It is obvious

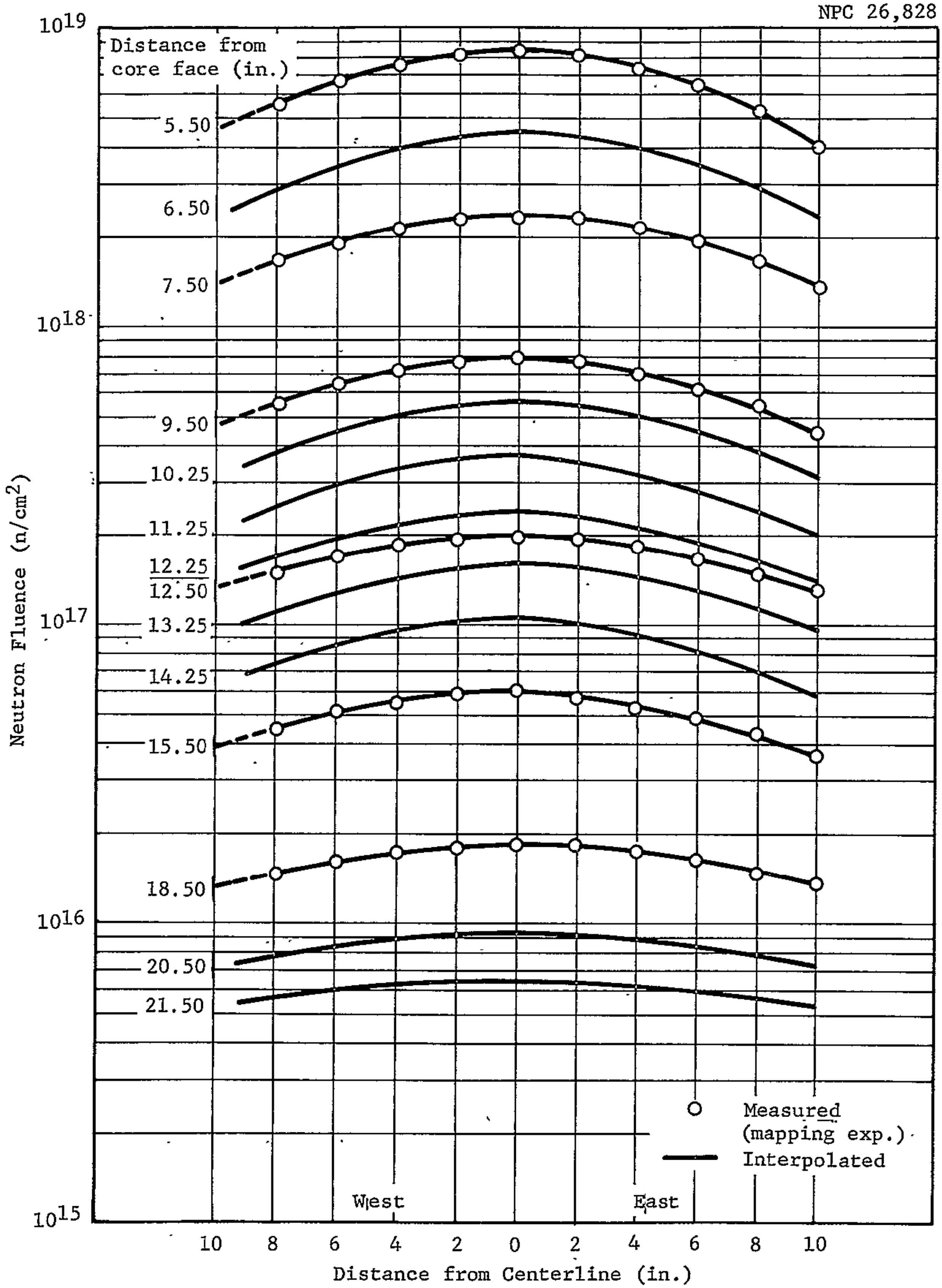


Figure A-4 Thermal-Neutron Fluence (E < 0.48 MeV) at Various Distances from the South Face of the GTR from Figures A-4 and A-5 that a positioning error in a direction normal to the reactor face is much more serious than a lateral (or vertical) positioning error.

For the thermal-neutron fluence, the following errors are estimated:

Interpolation (including weight and counting)	±5%
Buildup factor	±1%
Decay factor	±1%
Counting efficiency	±3%

The standard deviation of ±6% is an estimate of the precision of the individual values. By use of Figures 5-9 and A-1, which define the location of each specimen, and Figure A-4, which gives the fluence at each distance at which specimens were located, the thermal-neutron fluence for each specimen is defined.

The same procedure was employed for specifying the fast-neutron fluence (Fig. A-5), except that the mapping data were normalized to the GTR-21 data. There is a possibility that the GTR-21 data may actually be too high because of the contribution of a long-lived activity in the sulfur pellets at the time they were counted; however, when this was discovered, it could not be proved or disproved because of the low activity level of the pellets.

The gamma doses given in the data tables were taken from the profile curves in Figure A-6. These curves were derived from

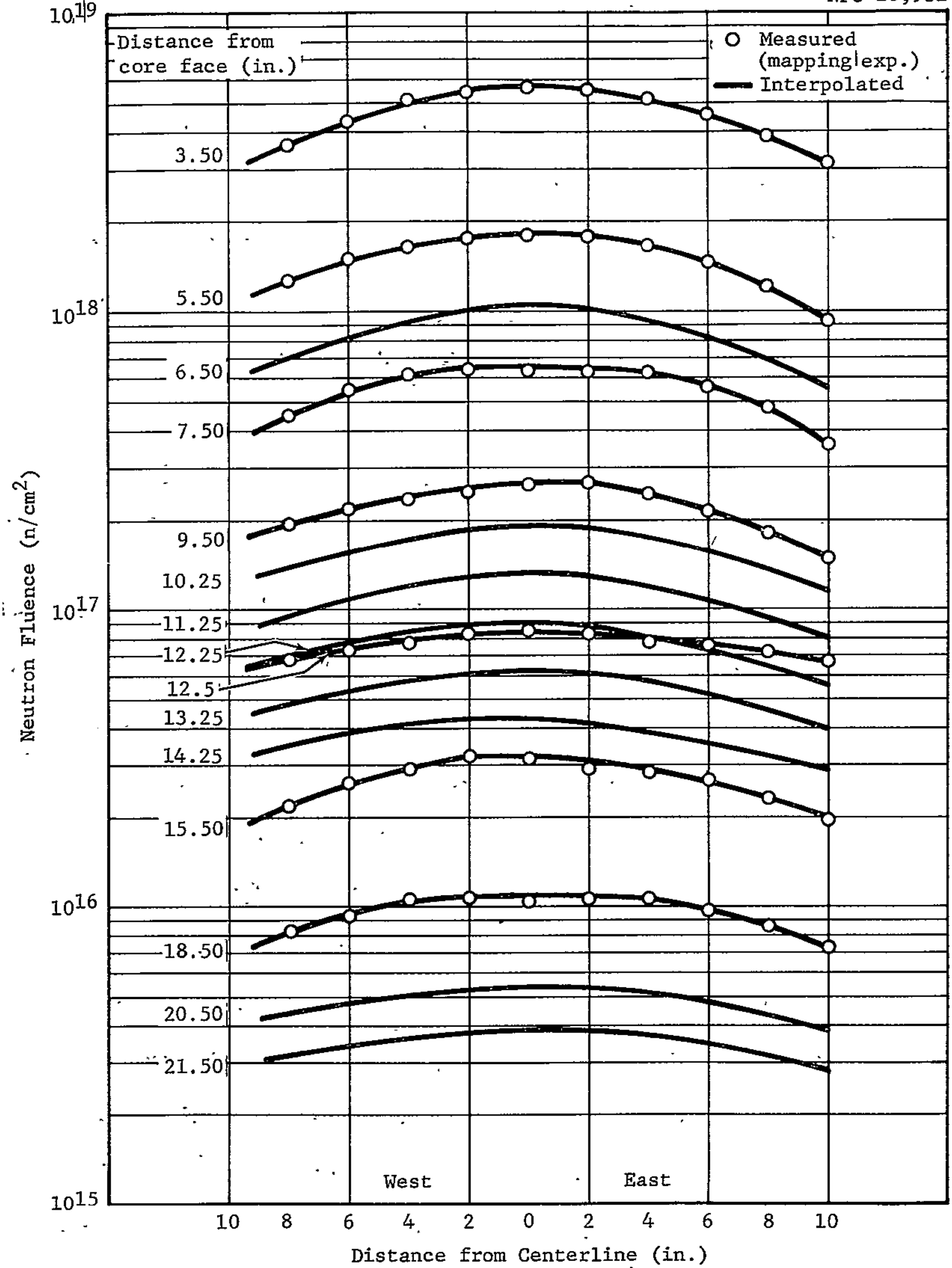


Figure A-5 Fast-Neutron Fluence (E > 1.0 MeV) at Various Distances from the South Face of the GTR

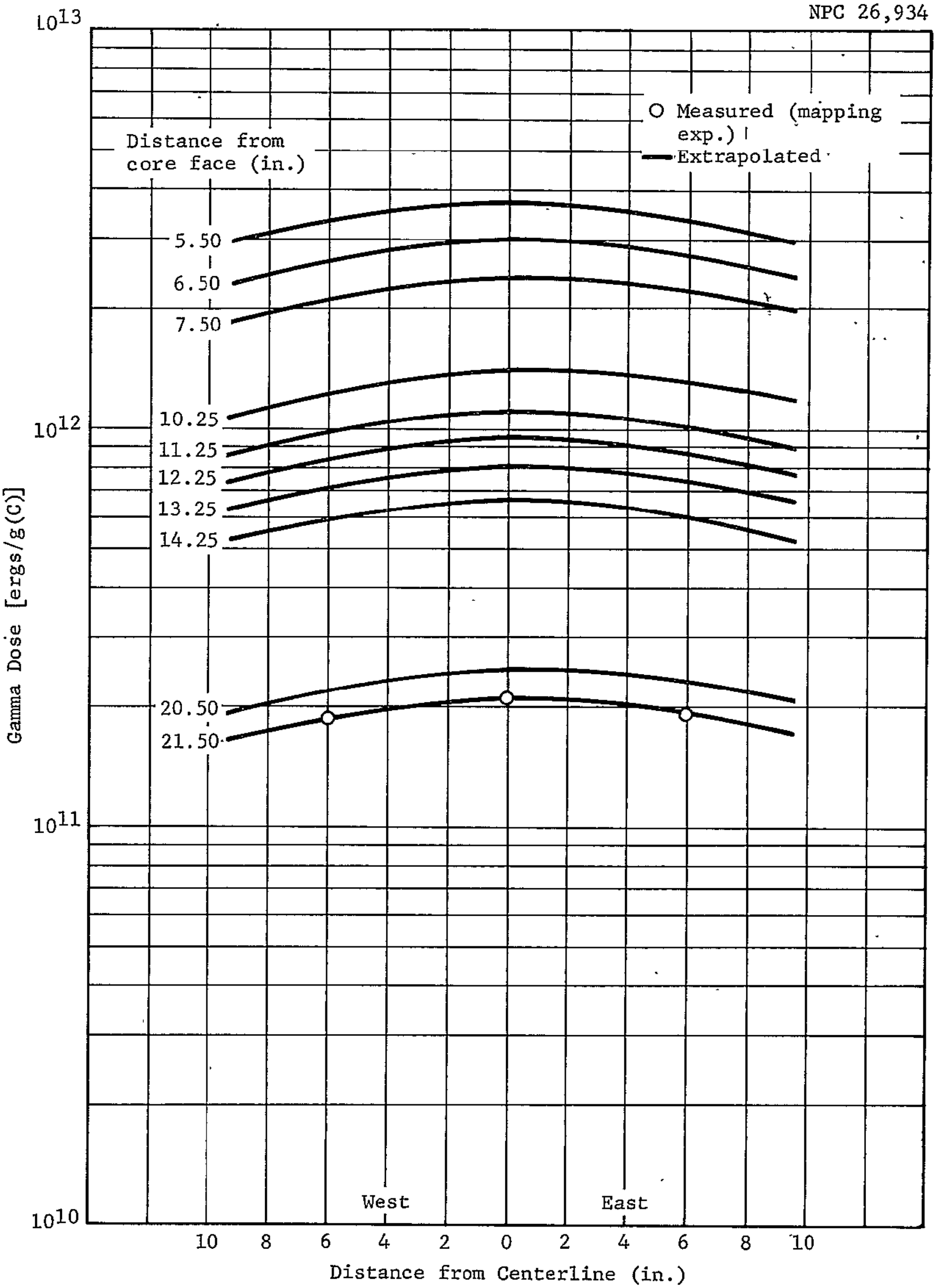


Figure A-6 Estimated Gamma Doses at Various Distances from the South Face of the GTR gamma doses measured 21.5 in. from the south face of the core during the mapping irradiation. The extrapolation from 21.5 to 5.5 in. is based on centerline water data as measured for the GTR and the Bulk Shielding Reactor at Oak Ridge National Laboratory. The results are probably good to within 50%.

A-3 General Comments on Neutron Dosimetry

The basic activation equation is

$$A(t) = N\sigma\phi\epsilon(BF)(DF) \quad (A\text{-}2)$$

where

$A(t)$ = the activity of a foil measured with a suitable detection system at a time t following exposure to a neutron flux ϕ

N = the number of atoms of target isotope

σ = the cross section for the desired reaction to occur

ϵ = the detection efficiency converting counts to disintegrations

BF = the buildup factor

DF = the decay factor

Therefore, in order to calculate a neutron flux ϕ from activity data A(t), five basic parameters are needed. Each of these parameters, as well as the measured activity, has some error which contributes to the error of the overall calculation.

A-3.1 Number of Atoms of Target Isotope

N is related directly to the weight of the foil and its isotopic purity. The quantity actually used is the isotopic foil weight, which is related to the number of atoms through

$$N_i = \frac{F_i \rho V\ A}{M} = \frac{F_i\ W\ A}{M} \tag{A-3}$$

where

N_i = the number of atoms of isotope i

F_i = the fractional isotopic concentration of i in the element

ρ = the density of the foil (g/cm^3)

A = Avagadro's Number (atoms/mole)

M = the atomic (isotopic) weight (g/mole)

V = the foil volume (cm^3)

W = the foil weight ($=\rho V$)

The fractional isotopic concentration is a well-known, experimentally determined quantity and is documented to several decimal places for all of the common elements in current use for flux measurements. Therefore, the uncertainty in isotopic concentration is negligible in comparison to other factors.

From Equation A-3, it would seem that reproducibility of weight for a given foil series would ensure the same reproducibility ot data, all other things being equal. However, since the routine counting procedures utilize end-window systems primarily sensitive to the detection of beta radiation from the activated isotopes, foil-weight reproducibility alone does not necessarily guarantee data reproducibility. In fact, experiments have shown that the counters are probably more sensitive to changes in foil area than changes in weight because of the degree of beta absorption in the foils. Nevertheless, weight is used as an index for production reproducibility and foil categorization. For foils of any given type and series, the weight factor is a constant consistent within 1-2% maximum deviation from a mean value. Reproducibility of foil area is maintained by cutting metallic foils with a special punch and by pressing the pellets in a steel die.

A-3.2 <u>Counting Efficiency</u>

The definition of counting efficiency, as used at NARF, implies a number used to convert counts to incident neutrons in Equation A-2. This number includes the influence of several factors such as:

- Foil dimensions and weight
- Intrinsic counting efficiency of the detector
- Geometrical relation between foil and detector
- Shielding arrangement
- Beta-particle absorption in the foil
- Correction factors for decay scheme
- Nonuniform activation in the foil

These factors are well documented in the literature, and foil calibration procedures used at NARF are discussed in detail in References 2, 3, and 4. Results obtained periodically over a number of years, both independently and with other participating agencies, indicate that relative standard deviations for counting efficiencies are typically on the order of 3%.

A-3.3 Buildup and Decay Factors

The activity of an irradiated foil decays with time with a decay constant characteristic of the activated isotope. For the foils of interest, the activation halflives, from which the decay constants are calculated, are sufficiently long and well known that slight error (less than 1%) is introduced by the decay constants. However, the irradiation time and decay time must also be accurately measured, which is not difficult for simple irradiations involving a single irradiation at a constant power level. For irradiations involving many startup and shutdowns, the computation of the buildup and decay factors becomes much more complex and the introduction of additional error is inevitable. With reasonable care in recording times and reactor power levels, the resultant uncertainty should not exceed 2%.

A-3.4 Cross Sections

The cross section for a given reaction is an intrinsic nuclear property of the isotope that defines the interaction probability of a target nucleus and the bombarding particle. The uncertainty in the absolute value of the cross sections for the commonly used neutron-detecting isotopes is typically from 10 to 20%. Cross sections of the isotopes used as thermal-neutron detectors are rather simple functions of neutron energy; being relatively easy to measure, these cross sections are in general the most accurately known. The fact that the neutron cross section is a function of neutron energy makes it useful for flux measurements, particularly for the fast (>1 MeV) energy region. At the same time, however, the complexity of the problem is increased by the complicated nature of the cross section vs energy function. Therefore, a certain amount of smoothing and averaging is required to obtain a consistent set of results, and a quantity known as the "effective cross section" is used in fast-flux measurements. The sulfur reaction is typical of reactions used for fast-flux calculations.

For neutron spectra similar to that of the GTR, i.e., a fission spectrum above about 1 MeV energy, sulfur has come to be a widely used detector. An effective cross section of 300 mb and an effective threshold of 2.9 MeV are generally accepted. A recent interlaboratory calibration experiment was performed with seven participants, including the Fort Worth Division. Five sulfur pellets supplied by each participant were exposed to five similar neutron fluences at the Northrop Triga Reactor. Activation data were subsequently accumulated by each laboratory independently and calculations performed. An agreement to ±14% was obtained, the

Division results being less than 5% higher than the overall mean. These results give a reasonably accurate picture of the overall reproducibility attainable.

A-3.5 Counting Statistics

A minimum of 10,000 counts is normally accumulated during each counting interval in order to obtain a 1% or less standard deviation in the average count rate. Several counts are usually obtained over a time period sufficiently long that the halflife can be checked. With multiple counts, an average saturated specific activity with a relative standard deviation of less than 1% is attainable.

A-4 Reactor Log

The reactor operating log for GTR 21 is given in Table A-2.

Table A-2

REACTOR LOG FOR GTR-21

Date (1967)	Time	Power Level (MW)	Elapsed Time (min)	Accumulated Exposure (MWh)
Oct 13				
	1741	6.0	2	0.2
	1743	7.0	73	8.6
	1856	5.0	64	14.0
	2000	4.9	600	63.0
Oct 14				
	0600	4.8	221	80.7
	0941	0.9	38	81.3
	1019	6.3	8	82.1
	1027	0.0	32	82.1
	1059	4.8	481	120.6
	1900	4.7	666	172.8
Oct 15				
	0606	4.6	791	233.4
	1917	2.3	82	263.5
	2039	4.6	1020	314.7
Oct 16				
	1339	7.1	146	331.9
	1605	7.2	1291	486.8
Oct 17				
	1336	4.0	5	487.2
	1341	0.7	10	487.3
	1351	7.2	457	542.1
	2128	4.0	5	542.5
	2133	7.2	806	639.2
Oct 18				
	1059	0.0	45	639.2
	1144	0.5	9	639.3
	1153	5.0	419	674.1
	1852	0.0	1491	674.1

Table A-2 (Cont'd)

Date (1967)	Time	Power Level (MW)	Elapsed Time (min)	Accumulated Exposure (MWh)
Oct 19				
	1943	7.2	181	695.9
	2244	0.0	22	695.9
	2306	7.2	144	713.1
Oct 20				
	0130	6.7	438	762.0
	0848	0.0	30	762.1
	0918	6.8	166	780.9
	1204	0.0	20	780.9
	1224	0.7	10	781.0
	1234	0.0	34	781.0
	1308	6.8	17	782.9
	1325	0.0	29	782.9
	1354	6.8	56	789.3
	1450	0.7	55	789.9
	1545	6.6	105	801.5
	1730	6.8	330	838.9
	2300	7.0	546	902.6
Oct 21				
	0806	0.0	1254	902.6
Oct 22				
	0500	7.2	240	931.4
	0900	6.8	30	934.8
	0930	6.7	30	938.1
	1000	6.6	90	948.0
	1130	6.5	9	949.0
	1139	0.0	28	949.0
	1207	6.5	653	1019.7
	2300	7.2	75	1028.7
Oct 23				
	0015	7.0	276	1060.9
	0451	6.7	119	1074.2
	0650	3.2	25	1075.5
	0715	6.7	225	1100.7
	1100	6.4	4452	1575.5

Table A-2 (Cont'd)

Date (1967)	Time	Power Level (MW)	Elapsed Time (min)	Accumulated Exposure (MWh)
Oct 26				
	1312	6.2	1002	1679.1
Oct 27				
	0554	6.4	258	1706.6
	1012	0.0	73	1706.6
	1125	6.4	1835	1902.3
Oct 28	1800	0.0	3732	1902.3
Oct 31				
	0812	0.0	11	1902.3
	0823	0.0	17	1902.3
	0840	5.0	4432	2271.7
Nov 3				
	1032	1.7	5	2271.8
	1037	0.0	9	2271.8
	1046	5.0	475	2311.4
	1841	Shutdown		

APPENDIX B

BENCH-MEASURED SPECIMEN DIMENSIONS

Tables B-1 through B-6 give the bench-measured dimensions for the cryogenic and high-temperature structural materials.

Table B-1

BENCH-MEASURED SPECIMEN DIMENSIONS FOR ALUMINUM 7039 AND HASTELLOY X (ROUND SPECIMENS)

Specimen Number	G.L. Diam (in.)		G.L. plus Shanks (in.)	
	Minimum Original	After Fracture	Original	After Fracture
A 01	0.2013	0.1672	2.502	2.7600
A 02	0.2008	0.1687	2.495	2.7115
A 03	0.2006	0.1625	2.502	2.7431
A 04	0.2002	-	2.504	-
A 05	0.1999	0.1604	2.502	2.7030
A 06	0.2010	0.1650	2.501	2.7170
A 07	0.1996	0.1664	2.501	2.7395
A 08	0.2000	0.1663	2.504	2.7408
A 09	0.2000	0.1655	2.498	2.720
A 10	0.2002	0.1655	2.497	2.734
A 11	0.1995	0.1659	2.499	2.724
A 12	0.1995	0.1647	2.501	2.7385
AW 01	0.2008	0.1689	2.502	2.675
AW 02	0.2000	0.1694	2.501	2.718
AW 03	0.2007	0.1667	2.499	2.692
AW 04	0.1995	0.1643	2.499	2.683
AW 05	0.2008	0.1612	2.499	2.681
AW 06	0.2000	0.1675	2.498	2.657
AW 07	0.1972	0.1688	2.500	2.680
AW 08	0.2009	0.1714	2.502	2.675
AW 09	0.1995	0.1641	2.488	2.665
AW 10	0.2010	0.1656	2.500	2.669
AW 11	0.2005	0.1648	2.500	2.709
AW 12	0.2012	0.1642	2.501	2.679

Specimen Number	G.L. Diam (in.)		G.L. plus Shanks (in.)	
	Minimum Original	After Fracture	Original	After Fracture
B 01	0.2018	0.1714	2.491	2.690
B 02	0.2005	0.1664	2.494	2.721
B 03	0.2005	0.1712	2.492	2.692
B 04	0.2004	0.1748	2.502	2.695
B 05	0.2005	0.1758	2.490	2.678
B 06	0.2005	0.1772	2.498	2.695
BW 01	0.2009	0.1618	2.498	2.620
BW 02	0.2006	0.1664	2.498	2.611
BW 03	0.2009	0.1629	2.490	2.649
BW 04	0.2010	0.1674	2.499	2.605
BW 05	0.2008	0.1724	2.496	2.595
BW 06	0.2007	0.1633	2.498	2.612
H 01	0.2003	0.1770	2.498	2.859
H 02	0.2003	0.1729	2.497	2.816
H 03	0.2004	0.1779	2.496	2.833
H 04	0.2001	0.1714	2.501	2.779
H 05	0.1990	0.1790	2.514	2.778
H 06	0.2006	0.1765	2.497	2.752
H 07	0.1988	0.1789	2.500	2.753
H 08	0.1990	0.1763	2.496	2.727
HW 01	0.2004	0.1779	2.499	2.732
HW 02	0.1990	0.1770	2.509	2.755
HW 03	0.1999	0.1783	2.502	2.741
HW 04	0.2001	0.1768	2.500	2.765
HW 05	0.2004	0.1805	2.498	2.700
HW 06	0.2000	0.1797	2.498	2.710
HW 07	0.1997	0.1795	2.500	2.691
HW 08	0.1979	0.1805	2.498	2.679

Table B-2

BENCH-MEASURED SPECIMEN DIMENSIONS FOR ALUMINUM 7039
(FLAT-NOTCHED SPECIMENS)

Specimen Number	Original Dimensions at Notch (in.)	
	Width	Thickness
A 15	0.7005	0.1860
A 16	0.7044	0.1862
A 17	0.7045	0.1880
A 18	0.7083	0.1875
A 19	0.7004	0.1860
A 20	0.7019	0.1890
AW 15	0.6794	0.1878
AW 16	0.6786	0.1845
AW 17	0.6827	0.1865
AW 18	0.6792	0.1850
AW 19	0.7034	0.1862
AW 21	0.6839	0.1860
B 09	0.7017	0.1890
B 10	0.7016	0.1895
B 11	0.7021	0.1889
B 12	0.7025	0.1905
B 13	0.7011	0.1908
B 14	0.7029	0.1891
B 16	0.7022	0.1878
BW 11	0.7024	0.1872
BW 12	0.7003	0.1885
BW 13	0.7043	0.1870
BW 14	0.7007	0.1895
BW 15	0.7016	0.1900
BW 16	0.7022	0.1888

Table B-3

BENCH-MEASURED SPECIMEN DIMENSIONS
FOR RENÉ 41

Specimen Number	Test Date 1968	G.L. Diam (in.)		G.L. plus Shank (in.)	
		Minimum Original	After Fracture	Original	After Fracture
R1 01	3-8	0.2001	0.1865	2.500	2.6479
R1 02	3-8	0.2001	-	2.500	-
R1 03	3-12	0.1988	0.1835	2.504	2.6699
R1 04	3-13	0.2002	0.1850	2.506	2.6048
R1 05	3-13	0.2004	0.1875	2.503	2.5801
R1 06	3013	0.2000	0.1825	2.502	2.6108
R1 13	3-14	0.2002	0.1935	2.499	2.5864
R1 14	3-14	0.1998	0.1855	2.499	2.5833
R1 15	3-14	0.2001	0.1900	2.506	2.5798
R1 16	3-13	0.2006	0.1885	2.502	2.5745
R1 17	3-13	0.2003	0.1935	2.504	2.5692
R1 18	3-14	0.1999	0.1885	2.503	2.5768
R2 07	3-13	0.2000	0.1860	2.503	2.6619
R2 08	3-13	0.1994	0.1900	2.503	2.5555
R2 09	3-13	0.2008	0.1895	2.503	2.5988
R2 10	3-14	0.1997	0.1960	2.503	2.5318
R2 11	3-15	0.2002	0.1945	2.503	2.5482
R2 12	3-28	0.2002	0.1910	2.501	2.5315
R2 19	3-28	0.1999	0.1950	2.498	2.5293
R2 20	3-28	0.2009	0.1960	2.501	2.5233
R2 21	3-28	0.1998	0.1900	2 498	2.5224
R2 22	4-2	0.1997	0.1810	2.501	2.6239
R2 23	4-2	0.1996	0.1835	2.501	2.6821
R2 24	4-2	0.1991	0.1800	2.502	2.6817
R2 26	3-14	0.2001	0.1915	2.506	2.5901

Table B-4

BENCH-MEASURED SPECIMEN DIMENSIONS FOR WASPALOY
(ROUND-UNNOTCHED SPECIMENS)

Specimen Number	Test Date 1968	G.L. Diam (in.)		G.L. plus Shank (in.)	
		Minimum Original	After Fracture	Original	After Fracture
W 01	3-8	0.1944	0.1650	2.500	2.8892
W 02	3-11	0.1995	0.1700	2.497	2.9178
W 03	3-11	0.1992	0.1605	2.498	2.9847
W 04	3-11	0.1956	0.1680	2.496	2.8710
W 07	3-12	0.1992	0.1760	2.498	2.8134
W 10	3-12	0.1968	0.1725	2.499	2.8815
W 12	3-14	0.1995	0.1570	2.500	2.9097
W 13	3-19	0.1998	0.1675	2.498	2.8425
W 16	3-19	0.1990	0.1650	2.500	2.8458
W 17	3-19	0.1978	0.1745	2.500	2.7750
W 18	3-20	0.1990	0.1745	2.499	2.8011
W 19	3-20	0.1995	0.1800	2.502	2.7410
W 20		0.1999	-	2.500	-
W 21	3-17	0.2003	0.1800	2.500	2.7401
W 22	3-18	0.2000	0.1775	2.502	2.7769
W 23	3-18	0.2000	0.1760	2.504	2.7127
W 24	3-18	0.1986	0.1795	2.498	2.7070
W 26	3-19	0.2000	0.1800	2.498	2.6998
W 27	3-14	0.1996	0.1945	2.501	2.8212
W 28	3-14	0.1990	0.1720	2.501	2.7969
W 29	3-20	0.1995	0.1735	2.502	2.7758
W 30	3-25	0.1995	0.1825	2.500	2.6732
W 31	3-25	0.1995	0.1860	2 500	2.6155
W 32	3-25	0.1990	0.1815	2.501	2.6298
W 34	3-20	0.1964	0.1825	2.502	2.6184
W 36	3-20	0.1998	0.1890	2.503	2.6248
W 37	3-21	0.1989	0.1865	2.498	2.6040
W 39	3-27	0.1990	0.1910	2.502	2.5866
W 40	3-27	0.1960	0.1885	2.512	2.5916
W 43	3-27	0.1995	0.1930	2.503	2.5597

Cont'd

Table B-4 (Cont'd)

Specimen Number	Test Date 1968	G.L. Diam (in.) Minimum Original	G.L. Diam (in.) After Fracture	G.L. plus Shank (in.) Original	G.L. plus Shank (in.) After Fracture
W 44	3-20	0.1996	0.1675	2.500	2.8531
W 45	3-20	0.1993	0.1715	2.500	2.8334
W 46	3-21	0.1995	0.1695	2.504	2.8689
W 47	3-22	0.1980	0.1650	2.501	2.833
W 48	3-29	0.1995	0.1720	2 500	2.777
W 50	4-16	0.1990	0.1800	2.500	2.706
W 53	4-26	0.1996	0.1865	2.496	2.616
W 54	5-6	0.1998	0 1875	2.500	2.614
W 56	5-16	0.1998	0.1860	2.496	2.606
W 57	4-22	0.2000	0.1860	2.502	2.612
W 58	5-2	0.1998	0.1860	2.498	2.625
W 60	5-8	0.1990	0.1850	2.507	2.639
W 61	4-19	0.1995	0.1855	2.503	2.595
W 62	4-28	0.1995	0.1860	2.499	2.609
W 63	5-12	0.1994	0.1900	2.502	2 580
W 67	3-20	0.1935	0.1610	2.504	2.8182
W 68	3-20	0.1995	0.1710	2.502	2.8322
W 70	3-20	0.1996	0.1695	2.499	2.8272
W 72	5-21	0.1997	0.1780	2.504	2.7157

Table B-5

BENCH-MEASURED SPECIMEN DIMENSIONS FOR INCONEL 718
(ROUND-UNNOTCHED SPECIMENS)

Specimen Number	Test Date 1968	G.L. Diam (in.) Minimum Original	G.L. Diam (in.) After Fracture	G.L. plus Shank (in.) Original	G.L. plus Shank (in.) After Fracture
N 02	3-4	0.2001	0.1535	2.527	2.7677
N 03	3-4	0.1997	0.1495	2.513	2.7823
N 04	3-21	0.2000	0.1820	2.496	2.6187
N 05	3-21	0.1994	0.1835	2.495	2.5746
N 06	3-22	0.2000	0.1860	2 496	2.5653
N 07	3-22	0.2004	0.1900	2 494	2.5694
N 08	3-5	0.1996	0.1785	2.545	2.7358
N 10	3-6	0.2002	0.1775	2.495	2.7677
N 11	3-6	0.2003	0.1775	2.502	2.6836
N 12	3-6	0.1995	0.1780	2.498	2.6549
N 13	3-6	0.1998	0.1840	2.496	2.6330
N 14	3-6	0.2002	0.1810	2.497	2.6538
N 15	3-7	0.1994	0.1810	2.499	2.6266
N 17	3-7	0.2000	0.1785	2.497	2.6325
N 19	3-7	0.1998	0.1810	2.527	2.6579
N 20	3-7	0.2003	0.1865	2.498	2.6104
N 21	3-7	0.1998	0.1810	2.497	2.6137
N 23	3-7	0.2002	0.1800	2.497	2.6253
N 24	3-5	0.2001	0.1835	2.502	2.5909
N 25	3-5	0.2004	0.1860	2.503	2.5741
N 26	3-5	0.2004	0.1875	2.496	2.5793
N 27	3-5	0.2001	0.1905	2.498	2.572
N 28	3-6	0.1998	0.1850	2.497	2.5543
N 29	3-6	0.2001	0.1895	2.497	2.5578
N 30	3-6	0.1996	0.1890	2.498	2.5487
N 31	3-6	0.1995	0.1875	2.500	2.5475
N 32	3-6	0.1995	0.1935	2.497	2.5525
N 33	3-6	0.1999	0.1925	2.496	2.5406
N 34	3-6	0.1998	0.1865	2.496	2.5351
N 35	3-6	0.2002	0.1935	2.497	2.5555

Cont'd

Table B-5 (Cont'd)

Specimen Number	Test Date 1968	G.L. Diam (in.)		G.L. plus Shank (in.)	
		Minimum Original	After Fracture	Original	After Fracture
N 36	3-4	0.2001	0.1725	2.498	2.6919
N 37	3-4	0.2002	0.1700	2.498	2.6847
N 39	3-4	0.1999	0.1690	2.503	2.6947
N 41	3-4	0.1999	0.1775	2.499	2.637
N 42	3-4	0.2000	0.1738	2.497	2.647
N 43	3-4	0.2000	0.1748	2.502	2.639
N 44	3-19	0.1998	0.1900	2.502	2.553
N 45	4-1	0.2002	0.1845	2.497	2.604
N 46	4-4	0.1992	0.1820	2.495	2.603
N 47	4-14	0.1994	0.1850	2.498	2.561
N 48	4-24	0.1998	0.1900	2.496	2.564
N 49	4-27	0.2002	0.1890	2.497	2.560
N 50	4-19	0.2002	0.1905	2.497	2.530
N 51	5-1	0.2008	0.1910	2.495	2.531
N 52	5-3	0.1992	0.1875	2.496	2.528
N 53	4-20	0.1996	0.1925	2.502	2.523
N 55	5-1	0.2002	0.1945	2.498	2.517
N 56	5-7	0.1999	0.1910	2.495	2.515
N 57	5-15	0.1998	0.1875	2.519	2.569
N 58	3-22	0.2002	0.1855	2.498	2.594
L 01	3-12	0.1997	0.1835	2.498	2.5326
L 02	4-2	0.1995	0.1885	2.498	2.5768
L 03	5-7	0.1995	0.1925	2.498	2.5270
L 04	3-8	0.1995	0.1835	2.498	2.5165
L 05	3-15	0.1980	0.1916	2.506	2.5673
L 06	4-2	0.1995	0.1945	2.497	2.5511
L 07	3-8	0.1996	0.1825	2.498	2.5387
L 08	4-11	0.1995	0.1905	2.498	2.5642
L 11	4-17	0.1994	0.1795	2.498	2.5453
L 12	3-12	0.1996	0.1875	2.498	2.5513
L 13	5-11	0.2001	0.1930	2.498	2.5437

Cont'd

Table B-5 (Cont'd)

Specimen Number	Test Date 1968	G.L. Diam (in.)		G.L. plus Shank (in.)	
		Minimum Original	After Fracture	Original	After Fracture
C 01	3-7	0.2007	0.1850	2.500	2.6129
C 02	3-7	0.2008	0.1900	2.505	2.5829
C 04	3-7	0.2000	0.1870	2.505	2.5718
C 05	3-7	0.2002	0.1825	2.505	2.5757
C 08	3-7	0.2004	0.1855	2.508	2.6014

Table B-6

BENCH-MEASURED DIMENSIONS OF WASPALOY AND INCONEL 718 (ROUND-NOTCHED SPECIMENS)

Specimen Number	Test Date 1968	G.L. Diam (in.) Minimum Original	G.L. Diam (in.) After Fracture	Notch Diam (in.)	G.L. plus Shank (in.) Original	G.L. plus Shank (in.) After Fracture
WS 01	6-1	0.1996	0.1710	0.1975	2.407	2.622
WS 02	6-4	0.2004	0.1660	0.1985	2.402	2.694
WS 03	6-5	0.2004	0.1905	0.1992	2.401	2.466
WS 04	6-7	0.2002	0.1895	0.1980	2.402	2.478
WS 05	6-8	0.2005	0.1910	0.1995	2.402	2.474
WS 06	6-6	0.2004	0.1950	0.1990	2.409	2.462
NS 01	5-22	0.2006	0.1945	0.2005	2.398	2.408
NS 02	5-25	0.2008	0.1860	0.2017	2.404	2.522
NS 03	6-1	0.2008	0.1980	0.2005	2.401	2.413
NS 04	6-5	0.2005	0.1955	0.1995	2.401	2.417
NS 05	6-4	0.2008	0.1975	0.2005	2.404	2.412
NS 06	6-6	0.2006	0.1970	0.2000	2.409	2.418
NS 07	5-28	0.2006	0.1725	0.2010	2.420	2.681

APPENDIX C

STANDARD DEVIATIONS OF PROPERTIES DATA

Table C-1 gives the pooled standard deviations and the degrees of freedom used in making the statistical comparisons of the effects of the various test conditions. The pooled standard deviation for a given property of a given material was obtained by combining all of the test data from both the control and irradiated specimens.

Table C-1

POOLED STANDARD DEVIATIONS AND DEGREES OF FREEDOM USED IN STATISTICAL COMPARISONS

Material	$\hat{\sigma}$ /degrees of freedom					
	Yield Stress	Max Stress	Fracture Stress	% Elongation Bench	% Elongation Chart	Area Reduct
Al 7039-T61, parent	0.38/7	0.29/7	0.61/7	0.91/7	0.69/7	1.62/7
Al 7039-T61, as welded	1.20/8	1.23/8	1.53/8	1.13/8	1.19/8	2.20/8
Al 7039-T64, welded and treated to T61	1.87/4	0.92/4	2.46/4	1.21/4	0.99/4	3.01/4
Al 7039-T64, parent	0.44/4	0.24/4	0.62/4	0.77/4	0.50/4	1.66/4
Al 7039-T61, parent (flat)	-	3.58/4	-	-	-	-
Al 7039-T61, as welded (flat)	-	2.05/4	-	-	-	-
Hastelloy X, parent	1.92/6	3.55/6	3.55/6	1.79/6	1.80/6	2.24/6
Hastelloy X, weldment	1.67/6	1.06/6	1.39/6	0.92/6	0.82/6	0.93/6
René 41	1.91/15	4.64/15	6.21/15	0.75/15	0.89/15	2.41/15
Waspaloy	3.68/23	2.26/23	5.33/23	2.26/23	2.46/23	2.63/23
Inconel 718	3.34/33	3.18/33	3.52/30	0.94/30	0.78/33	2.27/33

APPENDIX D

STRESS-RUPTURE DATA

The stress-rupture data given in Tables D-1 and D-2 were taken from the recorder charts of the Riehle Testers. The chart speed was a nominal 2 in./h, so many of the charts were several feet in length. Since small variations in the trace occurred with time, the procedure for reading the charts was as follows. Time intervals (2.5 or 5 h) were carefully marked off on the trace. A straight edge was then used to average any variations occurring around the time of interest. Having this value, a small zero offset (typically 1/200 of full scale) was subtracted. The resulting value was then converted to the proper scale.

Table D-1

STRESS-RUPTURE DATA FOR WASPALOY

Time (h)	Total Extension (in.)											
	Control			Low Dose			Medium Dose			High Dose		
	W 48	W 50	W 72	W 53	W 54	W 56	W 57	W 58	W 60	W 61	W 62	W 63
5	0.0300	0.0078	0.0128	0.0106	0.0118	0.0076	0.0114	0.0110	0.0198	0.0068	0.0160	0.0064
10	0.0496	0.0138	0.0234	0.0188	0.0208	0.0146	0.0200	0.0204	0.0336	0.0120	0.0304	0.0106
15	0.0648	0.0204	0.0334	0.0274	0.0300	0.0222	0.0288	0.0304	0.0460	0.0172	0.0416	0.0160
20	0.0780	0.0252	0.0420	0.0342	0.0384	0.0290	0.0354	0.0368	0.0550	0.0232	0.0520	0.0204
25	0.0902	0.0296	0.0494	0.0408	0.0450	0.0340	0.0416	0.0444	0.0648	0.0296	0.0610	0.0260
30	0.104	0.0350	0.0556	0.0476	0.0518	0.0416	0.0476	0.0510	0.0732	0.0364	0.0694	0.0320
35	0.119	0.0410	0.0626	0.0536	0.0576	0.0476	0.0536	0.0584	0.0826	0.0424	0.0780	0.0370
40	0.134	0.0458	0.0690	0.0592	0.0640	0.0536	0.0594	0.0652	0.0930	0.0468	0.0880	0.0424
45	0.150	0.0504	0.0744	0.0648	0.0708	0.0580	0.0650	0.0700	0.104	0.0522		0.0470
50	0.170	0.0554	0.0824	0.0692	0.0766	0.0634	0.0700	0.0780	0.113	0.0556		0.0520
55	0.194	0.0600	0.0882	0.0750	0.0832	0.0690	0.0756	0.0884		0.0592		0.0560
60	0.235	0.0642	0.0954	0.0812	0.0902	0.0736	0.0826	0.0946		0.0634		0.0614
65		0.0678	0.103	0.0884		0.0796	0.0868	0.103				0.0670
70		0.0718	0.108			0.0852	0.0946	0.116				0.0686
75		0.0744	0.114			0.0916	0.1016	0.115				
80		0.0784	0.123									
85		0.0828	0.130									
90		0.0850	0.138									
95		0.0878	0.145									
100		0.0924	0.165									
100[a]		0.0938	0.168									
101		0.0950	0.181									
101[a]		0.0962	0.183									
102		0.0990										
102[a]		0.101										
103		0.107										
103[a]		0.109										
104		0.120										
104[a]		0.121										
105		0.151										
105[a]		0.152										

[a] 5 ksi added

Table D-2

STRESS-RUPTURE DATA FOR INCONEL 718

Time (h)	Total Extension (in.)								
	Control			Low Dose			Medium Dose		
	N 45	N 46	N 57	N 47	N 48	N 49	N 50	N 51	N 52
5	0.0020	0.0018	0.0006	0.0020	0.0020	0.0014	0.0011	0.0022	0.0012
10	0.0030	0.0036	0.0014	0.0040	0.0028	0.0022	0.0022	0.0030	0.0026
15	0.0036	0.0054	0.0020	0.0052	0.0034	0.0032	0.0033	0.0042	0.0050
20	0.0046	0.0072	0.0034	0.0068	0.0040	0.0050	0.0045	0.0056	0.0076
25	0.0058	0.0090	0.0048	0.0082	0.0050	0.0068	0.0058	0.0078	0.0112
30	0.0072	0.0126	0.0074	0.0108	0.0060	0.0088	0.0078	0.0116	
35	0.0092	0.0200	0.0104	0.0152	0.0076	0.0130	0.0113	0.0194	
40	0.0126	0.0320	0.0154	0.0234	0.0092	0.0214	0.0155		
45	0.0170	0.0454	0.0214	0.0396	0.0120	0.0348			
50	0.0230	0.0670	0.0306		0.0166				
55	0.0310								
60	0.0452								
65	0.0744								

Time (h)	High Dose			Low Dose	Medium Dose	
	N 53	N 55	N 56	L 08	L 11	L 13
2.5	0.0012	0.0030	0.0006			
5.0	0.0034	0.0048	0.0008	0.0018	0.0020	0.0040
7.5	0.0037	0.0076	0.0016			
10.0	0.0040		0.0024	0.0029	0.0017	0.0010
12.5			0.0028			
15				0.0041	0.0035	0.0020
20				0.0054	0.0054	0.0038
25				0.0075	0.0072	0.0058
30				0.0098	0.0108	0.0068
35				0.0130	0.0174	0.0080
40				0.0206		0.0118
45				0.0290		0.0176
50				0.0416		0.0254

APPENDIX E

GTR RADIATION EFFECTS TESTING FACILITY

The GTR Radiation Effects Testing Facility is located in the Reactor Operations Area at the north end of the NARF complex. Figure E-1 is a plan view of the facility. Figure E-2 is a cutaway view of the irradiation test cell and the reactor tank. Figure E-3 is a photograph of the facility. During operation the reactor is moved into the closet-like structure built into the north wall of the GTR tank. Items to be irradiated are located near the bottom of the test cell at the north, east, or west sides of the closet, as indicated in the figures.

The reactor closet is constructed of 1-in.-thick aluminum plate and is partially covered by 1/4-in.-thick boral to attenuate thermal neutrons. The boral extends 36 in. east and west from the closet along the tank wall and 36 in. up and down from the horizontal centerline of the reactor core. The centerline is 57 in. above the test-cell floor.

The Ground Test Reactor is a heterogeneous, highly enriched, thermal reactor that utilizes water as neutron moderator and reflector, as radiation shielding, and as coolant. Maximum power generation is 10 MW. The GTR, in an aluminum enclosure to facilitate cooling-water flow, is suspended by an open framework that is carried on a horizontal positioning mechanism at the top of the

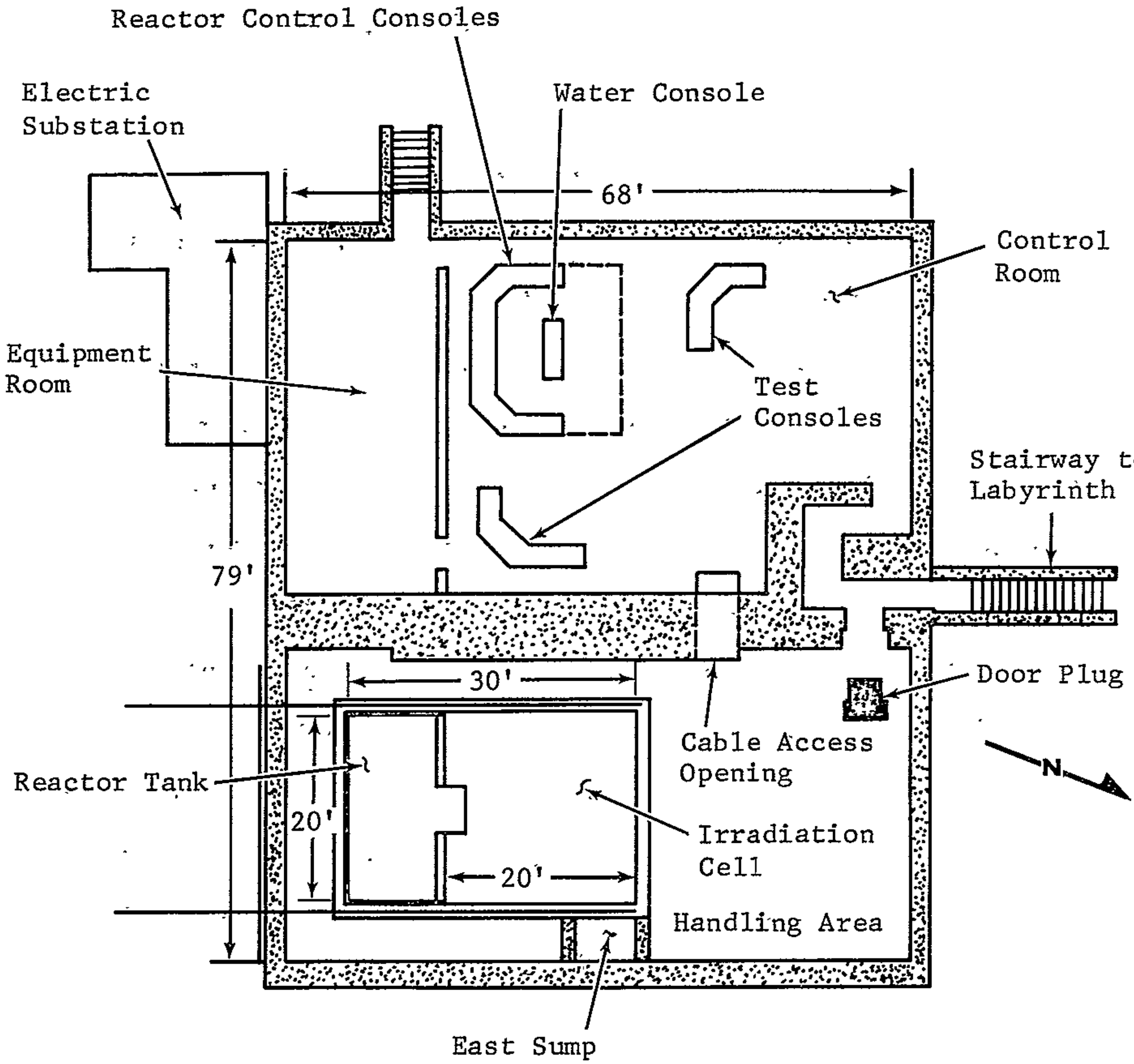
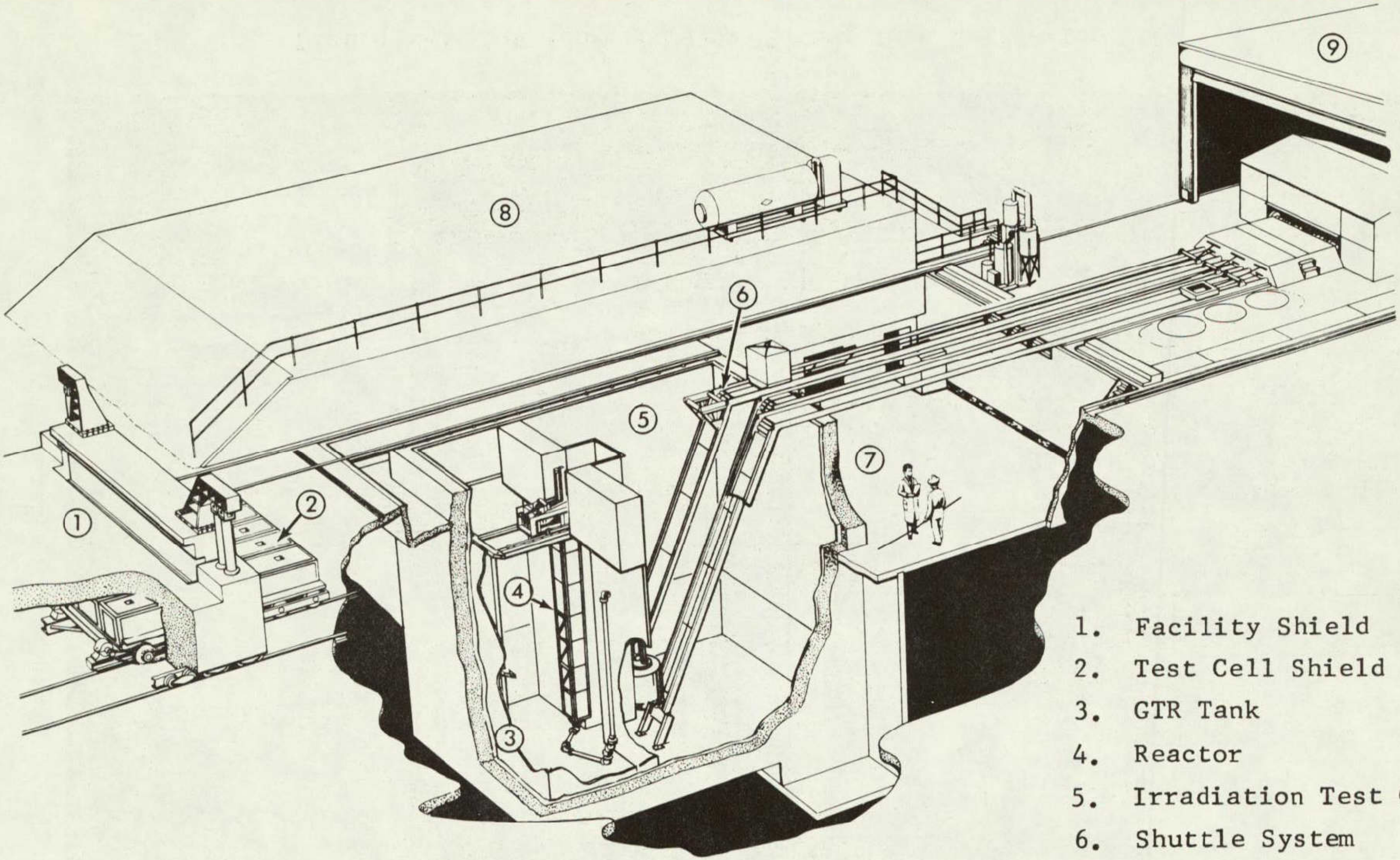


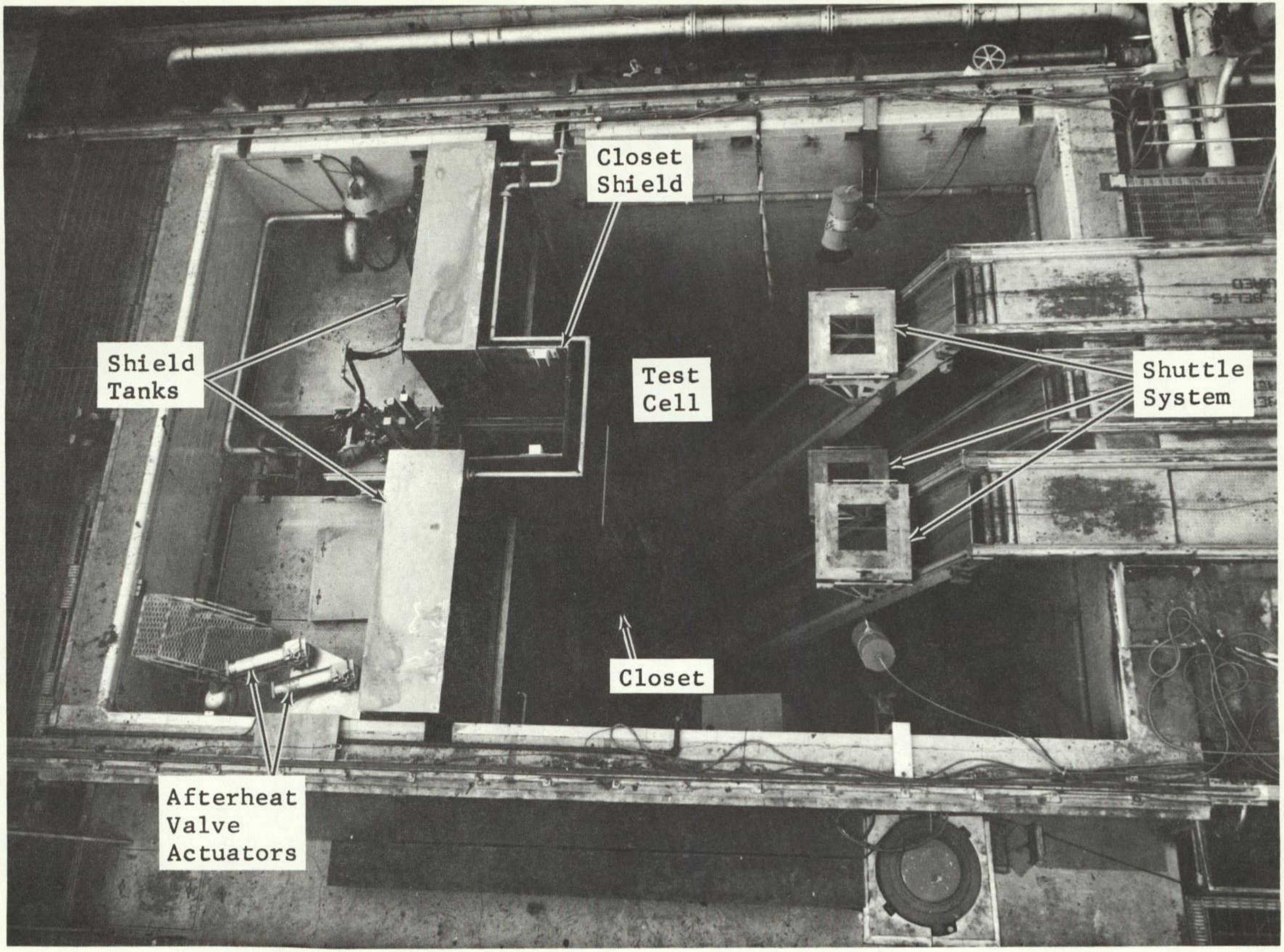
Figure E-1 GTR Radiation Effects Testing Facility



1. Facility Shield
2. Test Cell Shield
3. GTR Tank
4. Reactor
5. Irradiation Test Cell
6. Shuttle System
7. Handling Area
8. Control Room
9. Weather Cover

Figure E-2 GTR Tank and Irradiation Test Cell - Cutaway View

NPC 26,099



NPC 26,097
31-8887

Figure E-3 GTR Tank and Irradiation Test Cell - Top View reactor tank. This mechanism permits the reactor to be positioned at distances ranging from 2 to 87 in. from the north face of the closet.

Adjacent to the north wall of the irradiation cell is the handling area. In this area, various connections are made for cryogenic, hydraulic, and pneumatic equipment.

An integral part of the GTR testing facility is the shuttle system, which is used to move test assemblies into irradiation position. This system consists of cable-driven dollies mounted on three sets of parallel tracks. The tracks extend from the irradiation positions adjacent to the reactor closet, up an incline to the north wall of the irradiation cell, and to a loading area on the ramp just north of the handling area. The system can be operated from either the control room or the dolly motor-drive shed on the north ramp. Test setups that are incompatible with the shuttle system are positioned by means of an overhead crane.

The control room (see Fig. E-1) is a below-grade, reinforced-concrete structure adjacent to the GTR facility. The room provides a shielded area for reactor instrumentation, control consoles, and test systems, as well as special test equipment needed to conduct radiation experiments. Full-coverage televiewing of the irradiation cell, entire shuttle system, and general outside area is provided in the control room by means of closed-circuit television.

REFERENCES

1. Palmer, E. E., NERVA Irradiation Program, GTR Test 21, Volume 3 - Thermal Conductivity and Electrical Resistivity of Selected NERVA Materials, General Dynamics Fort Worth Division Report FZK 351-3 (NJD-20), 30 September 1968.

2. Bell, J. R., and Miles, J. K., Calibration of Foils for Neutron Flux Measurements, General Dynamics Fort Worth Division Report MR-N-279 (NARF-61-18T), June 1961.

3. Dungan, W. E., et al., Development and Application of Nuclear Measurement Techniques, AFWL Technical Report WL TR-64-160 (GDFWD Report FZK-208), March 1965.

4. Dungan, W. E., et al., Developmental Studies and Reliability Control in Nuclear Techniques for Radiation Effects Environmental Testing, AFWL Technical Report WL TR-66-14 (GDFWD Report FZK-276), August 1966.

DISTRIBUTION

ADDRESSEE	NO. OF COPIES
Headquarters USAF Washington, D. C. 20330 Attention: Mr. W. D. Downs (AFRDQSN)	1
SNPO-Cleveland Lewis Research Center 21000 Brookpark Road Cleveland, Ohio 44100 Attention: E. W. Miller	1
SNPO-Washington Division of Reactor Development U. S. A. E. C. Germantown, Maryland 20767 Attention: Mr. J. Morrissey	1
Aerojet-General Corporation P. O. Box 15847 Sacramento, California 95813 Attention: Dr. J. Conant	15
Aerojet-General Corporation P. O. Box 15847 Technical Library Bldg. 2015, Dept. 2410 Sacramento, California 95813	1
Westinghouse Astronuclear Laboratory P. O. Box 10864 Pittsburgh, Pennsylvania 15236 Attention: Mr. J. Coombe	5
SNPO-C Resident Office Aerojet-General Corporation Sacramento, California 95813 Attention: Mr. J. J. Fitts	1
Radiation Effects Information Center Battelle Memorial Institute 505 King Avenue Columbus, Ohio	1

GENERAL DYNAMICS

Fort Worth Division